Technical Report

Design, Development and Evaluation of the ES-2re Side Crash Test Dummy

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Prepared by:

OFFICE OF CRASHWORTHINESS STANDARDS
OFFICE OF APPLIED VEHICLE SAFETY RESEARCH
VEHICLE RESEARCH AND TEST CENTER

NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

Draft Technical Report on ES-2re Crash Test
Side Impact Dummy

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Executive Summary

This Technical Report addresses the NHTSA evaluation of the design, development and impact performance of the ES-2re dummy. The ES-2 dummy is a 50th percentile size side impact crash test dummy that was originally developed in Europe as the EuroSID-1 dummy in the late 1980s and the early part of 1990s. The dummy was designed to mimic the human dynamic response and to be used for the assessment of occupant protection provisions of motor vehicles in side impact crashes in European Union (EU) countries. Upon discovery of some deficiencies within the dummy, the EuroSID-1 was redesigned and reevaluated during the late 1990s and early 2000 with EU funding and renamed as the ES-2. The ES-2re dummy, covered in this Technical Report, is a further evaluation and development of the ES-2 incorporating rib extensions and additional modifications of the dummy's upper torso's back plate to prevent the "grabbing" interaction with the vehicle's seat back structure. The change will assure more human-like interaction of the dummy with the impacted vehicle's structure.

This Technical Report provides the background on how the dummy design evolved to its present stage. It discusses the dummy's design features and instrumentation provisions for injury assessment purposes, and provides data on the response of the dummy to impact stimulus at the component, subsystem and system levels. In addition, the report provides data on how well the dummy meets the goals of biofidelity, its capability for repeatable and reproducible impact response, and its mechanical durability and ability to function correctly under overload conditions. It also assesses the dummy's sensitivity to changes in impact direction. In addition, the report assesses the dummy's ability to address the potential of occupant injuries through instrumented readings in vehicle side impact crash tests.

The agency evaluation of the ES-2re dummy shows that it successfully resolved the back plate "grabbing" problem in those environments in which grabbing would have occurred with the ES-2 dummy. The ES-2re dummy satisfactorily met all of the calibration-certification requirements and was found to be of equal biofidelity as the ES-2 dummy. Its impact responses fell into excellent-to-good repeatability and reproducibility categories. The ES-2re dummy, during an extensive and very robust evaluation program, developed no structural deficiencies and/or durability problems. Its instrumentation provided continuous and useful measurements even in overload exposures.

Originally the EuroSID-1 dummy was designed, developed and manufactured in Europe primarily for EU and several other overseas users. Following the release of the ES-2 dummy by EEVC in 2001, two U.S. based dummy manufacturers began its production in the United States. While the EEVC in its final report on the ES-2 dummy noted that the back plate "grabbing" is still a technical problem that awaits final resolution in the United States, the EuroNCAP began use of the ES-2 dummy in 2004 in its vehicle rating program with point penalties for exceeding certain back plate loading limits.

NHTSA testing had found no detectable differences in design and performance between the U.S. and European built ES-2 dummies. With WP 29 announced intention in its June 2003 meeting to specify the ES-2 type dummy for side impact protection purposes upon successful resolution of the back plate problem, it appears that the ES-2 re has met these goals and can now become the first truly harmonized crash test device for world wide use.

Chapter I. Introduction

The ES-2 dummy is a 50th percentile size male side impact crash test dummy that was originally developed in Europe as the EuroSID-1 dummy in the late 1980s and the early part of 1990s [1]. The dummy was designed to mimic the human dynamic response and to assess the type and severity of injury that would be experienced by motor vehicle occupants in side impact crashes. The EuroSID-1 dummy was redesigned and renamed as the ES-2 in the late 1990s and early 2000 [2]. The ES-2re dummy, covered in this Technical Report, is a further evaluation and development of the ES-2 with provisions to prevent the grabbing interaction of the dummy's back by the vehicle's seat back structure and thus potentially preventing the dummy from human like interaction with the impacted vehicle structures.

This technical report provides details on the ES-2re dummy design and its evaluation by the agency for suitability as the side impact test device in the evaluation of occupant safety provisions of motor vehicles in lateral crashes. The report contains background information on how the dummy design evolved to its present stage, discusses the dummy's design features and instrumentation provisions for injury assessment purposes, and provides data on the response of the dummy to impact stimulus at the component, subsystem and system levels. In addition, the report provides data on how well the dummy meets the goals of biofidelity, its capability for repeatable and reproducible impact response, its mechanical durability and ability to function correctly under overload conditions, and sensitivity to changes in impact direction. The report also includes the dummy's response measurement capabilities in vehicle crashes such as moving barrier impacts, pole crashes, and in air bag exposures.

While originally the dummy was designed, developed and manufactured in Europe, it is now also being produced within the United States by at least two manufacturers. Agency testing had found no detectable differences in design and performance between the U.S. and European built dummies. This should facilitate use of the same side impact dummy for the development of occupant protection systems on a worldwide basis. Since the ES-2re dummy is more biofidelic and is equipped with considerably more instrumentation than the SID dummy presently used in the United States, it will enable the automotive safety community to develop, build and assure better protection for the motoring public in side impact crashes.

Chapter II. Background

II.1 Brief history of EuroSID-1 and ES-2 dummy development

The agency published on October 30, 1990, a final rule amending Federal Motor Vehicle Safety Standard (FMVSS) No. 214, "Side Impact Protection"[3]. The rule specified a dynamic side impact test for passenger cars aimed to enhance occupant protection in vehicle-to-vehicle side collisions. The compliance requirements would be demonstrated using impact response measurements with the 50th percentile size Side Impact Dummy (SID) [4]. On July 28, 1995, the agency published another final rule [5] requiring light trucks, buses and multipurpose passenger vehicles (LTVs 6000 lbs or less) to comply with the dynamic side impact requirements of passenger cars.

In parallel, the agency has followed with interest the development of the EU side impact regulation since its inception in the 1980s. The level of interest increased considerably with the completion of the EuroSID prototype development in the late eighties and the publication of Directive 96/27/EC by the European Parliament and the Council of the European Union in July 1996 [6]. Directive 96/27/EC dealt with side impact resistance requirements for motor vehicles and its Appendix 3 contained specifications for the EuroSID dummy. Since the publication of EU directive, the EuroSID has been specified as a side impact regulatory test device in Europe, Japan, and Australia. The EU side impact directive is mandatory to new and redesigned vehicles in the 1999 model year and will apply to all vehicles starting in the 2004 model year.

In 1997, based on NHTSA's side impact harmonization plan submitted to the US Congress [7], the agency performed a series of side impact research crash tests using the EU 96//27/EC test procedure and the EuroSID-1 dummy [6]. A main finding from the tests was that plateaus, termed "flat-top" behavior, were present in the dummy rib deflections for all the tests performed. Rib deflection flat tops are of concern, particularly at low levels of deflection, as they can be an indication that the rib deflection mechanism is binding and thus the thorax is not responding correctly to the load from the intruding side structure.

In 2000, TNO Automotive upgraded the EuroSID-1 dummy to ES-2. The ES-2 was developed mainly to address concerns raised by users of the dummy [8,9]. They observed that the ES-2 has:

- "Flat tops" in the rib deflection responses, attributed mainly to binding in the rib modules and interference of the torso back plate;
- Produced back plate grabbing of the seat back of the vehicle tested;
- Produced undesirable noise in the responses when the upper femur contacted the pubic load cell hardware;
- Produced binding in the shoulder assembly resulting in limited shoulder rotation
- Generated spikes in the pubic symphysis load measurements associated with knee-to-knee contact

The more important hardware upgrades introduced in the ES-2 dummy described in [2,8,9] are as follows:

- An improved rib guide system in the thorax;
- A curved and narrower back plate including a load cell to measure the load imparted to the dummy's skeletal structure through the back plate;
- New attachment in the pelvis to increase the range of upper leg abduction and inclusion of rubber buffers
- A high mass flesh system in the legs
- Beveled edges in the shoulder assembly

Further details of the above dummy improvements may be found in Annex A of reference [2].

In May 2000, NHTSA responded to a petition for rulemaking by US industry and insurance groups [10]. The petitioners in effect asked to replace FMVSS 214 with the Directive 96/27/EC using an upgraded version of the EuroSID-1 dummy when it becomes available. The agency granted the portion of the petition that requested NHTSA to consider replacing the side impact test dummy currently specified in the U.S. standard with an improved version of the dummy specified in the European regulation. All other aspects of the petition were denied [11].

Since the introduction of the ES-2 prototype in early 2000, NHTSA has been evaluating the dummy to assess its performance in the FMVSS 214 test configuration. The evaluation included dummy performance in component calibration tests, biofidelity sled tests, and full-scale crash tests. The agency test results showed that the shortcomings of the EuroSID-1, outlined above, have been addressed by the ES-2, with the exception of the potential of the dummy back plate "grabbing" by the approaching seat frame structure of the vehicle tested. Substantial localized loads to the dummy through the back plate demonstrate this grabbing as it is pushed laterally inboard away from the intruding structure. In effect, "grabbing" of the dummy back plate by the seat frame off-loads the thorax and limits rib deflections. In August 2001, EEVC Working Group 12 reported that a majority of test results comparing EuroSID-1 and ES-2 showed generally reduced back plate loads, but not their complete absence [2]. In June of 2002, First Technology Safety Systems (FTSS) developed a solution (retro-fix) to the back plate loading problem by enclosing the gap in the ES-2 rib cage between the end of the ribs and the back plate. The evaluation of the ES-2 with the rib extension fix (ES-2re) in both sled and full scale crash tests, as noted in this report, indicate that the shortcoming of the ES-2 back plate either locking into or grabbing the seat back has been resolved.

II.2 Perspective on injuries and injury assessment in side crashes that the dummy must address

While differences in fleet compositions and crash involvement worldwide may preclude totally harmonized test conditions, the use of a single dummy in side impact standards worldwide would alleviate current burdens of employing multiple types of test dummies in vehicle development and certification. Common dummies may also promote more rapid development of improvements in occupant safety. However, to assess the suitability of a dummy for side impact testing, it is necessary to consider the dummy's injury assessment capabilities relative to human body regions at risk in the real world crash environment, which may vary between different regions of the world and even between individual countries.

II.3. Vehicle Occupant Injuries in Side Impact Crashes

Side crashes in the United States produce serious injuries to around 31,000 vehicle occupants per year. Table II-1 shows the average annual injury distribution of the estimated target population in all types of side impact crashes between 12 and 25 mph delta V in the NASS/CDS 1988-99 data base [12]. Of these approximately 35% are small stature occupants.

Table II-1. U.S. Motor Vehicle Occupant Injury Severity Distribution in Side Crashes (NASS/CDS 1988-99; for delta-V of 12-25 mph)

Body Region	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatality	Total
Head & Face	11559	3209	175	342	408	1160	16853
Thorax	7546	508	2388	1847	32	1118	13439
Abdomen	454	150	40	308	77	240	1269
Pelvis	0	0	241	0	0	14	255

The remaining injured occupants fall into midsize and large segments of the population as shown in Table II-2 below.

Table II-2. U.S. Motor Vehicle Occupant Mid-size and above Injury Severity Distribution in Side Crashes(for delta-V of 12-25 mph)

Body Region	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatality	Total
Head & Face	7513	2086	114	222	265	754	10954
Thorax	4905	330	1553	1201	21	727	8737
Abdomen	295	98	26	200	50	156	825
Pelvis	0	0	156	0	0	9	165

The ES-2re dummy is well equipped to address all of the above noted body segment injuries. It includes the measurements of head acceleration for HIC, neck injuries via response measurement by upper and/or lower neck load cells, thoracic injuries in terms of spine and rib accelerations and rib deflections, abdominal injuries through three load cell measurements to assess the magnitude of lateral and oblique forces, pelvis acceleration and load on the pubic symphysis, a load cell between the pelvis and the lumbar spine to determine the load transfer between the upper and the lower torso halves, load cells to measure the back of the torso interaction with the vehicle seat back, and femur loads to measure the impact severity of the vehicle structure on the legs. In addition, in response to EuroNCAP requirements, a clavicle load cell is available as an option.

The ES-2re dummy has articulated arms that allow them to be placed at the side of the thorax. In this position the impacted arm acts as an interposer between the vehicle interior and the chest. The arms may also be swung up to several positions, leaving the thorax and the abdomen exposed to direct contact by the vehicle interior.

II.4 Commercial Availability of ES-2 re Dummies

There are several hundred EuroSID-1 dummies available throughout the world. Although the ES-2 dummy is still a relative newcomer, more than 100 of them are being used in EuroNCAP and other side impact programs in Europe, Asia, and to a lesser extent in North America. The dummy is readily available through First Technology Safety Systems (FTSS) and Denton ATD. The ES-2re version of the ES-2 dummy, containing back plate revisions is just a little over one year old. It is available either as whole ES-2re upper thorax assembly or as conversion kit needed to modify the existing ES-2 dummy to ES-2re. Approximately 10 conversion units have been delivered to commercial users.

Chapter III. ES-1 and ES-2 in World-wide Use

EuroSID-1 is currently incorporated in ECE Regulation 95, the European Union Directive 96/EC/27 test procedure [13], and used as the side impact regulatory test device in both Europe and Japan. It is also an optional regulatory test device in Australia. The EuroSID-1 has also been used in side impact crash testing by Transport Canada, and, to the best of our knowledge, in limited testing by the U.S. car manufacturers.

In June 2003, based on the proposal from the Netherlands, the U.N./ECE/GRSP agreed to recommend to WP.29 and the Executive Committee (AC.1), under the 1958 Agreement, the adoption of the ES-2 dummy in the ECE side impact regulation over a three-year phase-in period with the possibility of incorporating the ES-2 with the rib extension fix (ES-2re) upon its evaluation by NHTSA. This recommended amendment to ECE Regulation 95 was transmitted to WP.29 and AC.1 and adopted at the November 2003 meeting. As of January 2003, the ES-2 was incorporated in the EuroNCAP side impact test protocol [14] and has been in-use in crash tests performed to date under that program.

In 2002, The US Occupant Safety Research Partnership (OSRP) and Transport Canada conducted tests to establish a biofidelity rating for the ES-2 and compare full scale crash test data with the EuroSID-1 [15]. In parallel, NHTSA evaluated the ES-2re by the biofidelity ranking method [16]. Test results are contained in Chapter VII of this Technical Report.

Chapter IV. Description of the ES-2re dummy

IV.1. Overall description

The ES-2re dummy is of the same basic construction as the ES-2 dummy which is nearly identical to EuroSID-1, except for several revisions as noted in Annex A of [2]. The EuroSID-1 dummy is defined in Appendix 3 of the EU directive 96/27/EC of July 1996 [2] as having the following features:

- Dimensions and masses of a 50th percentile adult male;
- Structural composition consisting of a metal and plastic skeleton covered by flesh-simulating rubber, plastic and foam;
- Equipped with instrumentation and conforming to calibration requirements outlined in the provisional technical specifications and certification procedures of ref. [2].

IV.2. ES-2re dummy's construction

The ES-2re dummy, an upgrade of the ES-2 dummy, is defined in drawing 190-0000. It is constructed in a seated posture for side impact testing as shown in Figure IV-1. The rib extension revisions to the ES-2 dummy incorporate rib extensions and modification in the back plate area to minimize interaction of the torso back plate with the vehicle seat back (Attachment 4.b). The ES-2re drawing and specification package will be available for viewing and copying in the NHTSA electronic docket section.

This chapter describes in general terms the construction of the dummy's major body segments, and provides key anthropometric dimensions and mass distributions. Listing of all sensors and their general location within the dummy are described in Section IV.3. The dummy's conversion from left to right sided impacts is provided in Section IV.4.

IV.2.1. Head

The ES-2re head (part #190-1000) design is the same as that of the Hybrid III 50th percentile male dummy. It consists of an aluminum shell covered by a pliable vinyl skin. The interior of the shell is a cavity accommodating tri-axial accelerometers and a ballast.

IV.2.2. Neck

The neck assembly (part #190-2000) is a multi -element unit based on the EuroSID-1 dummy's neck. It consists of a molded cylindrical shaped flexible rubber element with attachment plates integrated at both ends. Circumferential grooves in the rubber cylinder determine the profile of the neck's bending stiffness characteristics. Interface plates link the attachment of the neck to the head and the thorax by means of a half spherical screw and eight rubber buffers, which provide a point of rotation at the top and bottom of the neck.

Figure IV-1. ES-2 dummy in seated posture prior to side impact test

The neck is attached to the torso through an adapter bracket. The angle between the two faces of the neck adaptor bracket is 25 degrees. Because the shoulder block is inclined 5 degrees backwards, the resulting angle between the neck and torso is 20 degrees. This angle approximates the head orientation relative to the torso of an in-vehicle seated human. Lateral neck flexion stiffness can be calibrated with replaceable neck buffer elements. The ES-2 dummy can be equipped with a six-axis upper neck load cell at the head-neck junction to evaluate neck injury and head contact loads. A lower neck six-axis load cell is available as an option.

IV.2.3. Shoulder

The ES-2re shoulder structure, upon lateral impact, allows the shoulder's ventral motion about the superior inferior axis, but not vertical displacement. The shoulder assembly (part #190-3000) consists of a shoulder block, two clavicles, and a shoulder cap. The shoulder block is made up of an aluminum spacer block, and horizontally oriented aluminum plates on top and the bottom of the spacer block. They are covered with low friction coating to minimize the binding within the shoulder during the clavicle rotation. The clavicles are made of polypropylene. They are held back in their neutral position by two elastic cords, which are affixed to the rear of the shoulder block. The shoulder-clavicle contains provisions for mounting of a stub arm and for ventral motion (rotation about superior-inferior pivot) from its design position approximately 27 degrees. The shoulder cap is made of low-density polyurethane foam and is attached to the shoulder block.

IV.2.4. Thorax

The ES-2re thorax assembly (part #190-4000) is a modification of the ES-2 design in the thorax back plate area. It consists of a rigid thoracic spine box and three identical rib modules. The rib module consists of a steel rib covered by flesh-simulating polyurethane foam, a piston-cylinder assembly linking the rib to the spine box, a hydraulic damper, and a stiff damper spring. In the piston-cylinder assembly is a tuning spring. A displacement transducer is mounted on the front face of the cylinder and connected to the inside of the rib. The top surface of the thoracic spine box is inclined 5 degrees. The EuroSID-1 rib piston guide was replaced by a new guide system based on standard needle bearings to reduce friction. The ES-2re contains a new back plate, rollers, Teflon cover and rib design to enclose the gap in the ES-2 dummy between the end of ribs and the back plate. The extended ribs provide a continuous surface at the back of the upper torso, which is intended to prevent interlock with the seat back surface during the crash test. This avoids unrealistic dummy kinematics and flat topping within the rib displacement curve. A four-axis load cell was incorporated to measure load transfer from the seat back to the spine. Details of the rib extension design are found in Attachment 4b. The current ribcage design limits the rib compression to a maximum of approximately 55 mm. A neoprene jacket covers the entire upper torso assembly.

IV.2.5. Lumbar spine

The ES-2re lumbar spine (part #190-5500) is the same as that of ES-1. The lumbar spine consists of a solid rubber cylinder with two steel interface plates at each end and a steel cable inside the cylinder. A T12 load cell has been added to the ES-2re dummy to measure load transfer between the upper and lower torso halves.

IV.2.6. Abdomen

The ES-2re abdomen (part #190-5000) is of the same type as the ES-1 design. It consists of a cast aluminum drum with a polyurethane foam covering. A curved slab of rubber, filled with lead pellets, is integrated in the foam covering at both sides. Three force transducers are mounted between the foam covering and the rigid casting at each side of the abdomen to measure the penetration forces transferred through the abdomen. The abdomen has been updated to improve its biofidelity and reliability.

IV.2.7. Pelvis

The ES-2re pelvis (part #190-6000) is of the same type as ES-1 design except for revisions in the hip socket area. The pelvis consists of a sacrum block, right and left polyurethane iliac wings, two hip joints, and a foam covering. The sacrum is a lead filled aluminum block covered on top by an aluminum plate. The hip joints are made of steel. They consist of an upper femur and a ball joint, which is connected through a hip socket to a steel plate on the iliac wing. The iliac wings are linked together at the pubic symphysis by a force transducer. A vinyl skin over urethane foam molding simulates the pelvis flesh with foam insert at the trochanter. The revised pelvis hip joint has an increased size bearing allowing 19 deg. of upper leg abduction. A rubber bumper at inside of the H-point plate is being contacted at 15 deg. of abduction, with the remaining 4 deg. available to damp the contact.

IV.2.8. Legs

The ES-2re legs (part # 190-7000-1 and-2 for left and right, respectively**)** are of the standard Hybrid II type design except for the femur bone and thigh flesh. These parts were modified for a more human-like bone-flesh mass distribution. The femur bone is made of a rigid lightweight metal covered by soft flesh consisting of high-density foam. Tri-axial or six axis femur load cells can be fitted to the dummy**.**

IV.2.9. Arms

The dummy's left and right half arms (part #190-3500-1 and–2, respectively) have plastic skeletons covered by polyurethane flesh and PVC skin. The shoulder/arm joint allows for discrete arm orientation in the sagittal plane at 0 deg., 40 deg. and 90 deg. with respect to the torso line.

IV.2.10. The dummy's anthropometry and mass distribution

The dummy's anthropometry and mass distribution are shown in Table IV-1.

IV.3. Sensors

The dummy requires for regular ECE purposes a minimum of 12 separate instrumented measurements, but has built in provisions to mount as many as 47 sensing units. Available sensors for the dummy are shown in Table IV-2 and sensor locations in Figure IV-1. Also Optional tilt sensors are available to measure the set-up angle for the thorax and pelvis.

Table IV-1 Anthropometry and Mass

	Dimension Spec (mm)	**Tol. (+/-)**
Sitting Height	909	9
Seat to Shoulder Joint	565	7
Seat to Lower Face of Thoracic Spine Box	351	5
Seat to Hip Joint (center of bolt)	100	3
Sole to Seat, Sitting	442	9
Head Width	155	3
Shoulder/Arm Width	470	9
Thorax Width	327	5
Abdomen Width	280	7
Pelvis Lap Width	366	7
Head Depth	201	5
Thorax Depth	267	5
Abdomen Depth	199	5
Pelvis Depth	240	5
Back of Buttocks to Hip Joint (center of bolt)	155	5
Back of Buttocks to Front Knee	606	9

Segment	**Mass (kg.)**	**Tol. (+/-)**
Head	4.00	0.20
Neck	1.00	0.05
Thorax	22.40	1.00
Arm	1.30	0.10
Abdomen	5.00	0.25
Pelvis	12.00	0.60
Leg	12.70	0.60
Total	72.00	1.20

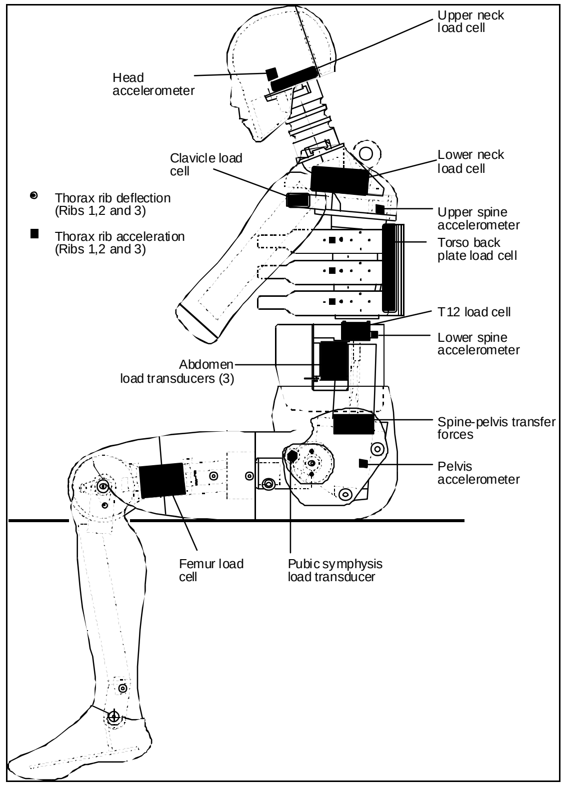

Figure IV-2 Instrumentation Location in ES-2

Table IV.2 ES-2 Instrumentation

Location	Description	Channels
Head	Tri-axial Accelerometer Pack	Ax, Ay, Az
Neck	Six Axis Upper Load Cell	Fx, Fy, Fz, Mx, My, Mz
	Six Axis Lower Load Cell	Fx, Fy, Fz, Mx, My, Mz
Clavicle	Three Axis Load Cell	Fx, Fy, Fz
Upper Torso/ Thorax	3 Rib Displacements	Dy
	3 Rib Accelerations	Ay
	Four Axis Torso Back Plate Load Cell	Fx, Fy,My, Mz
	Tri-axial Accelerometer Pack	Ax, Ay, Az
Abdomen	Abdomen Four Axis T12 Load Cell	Fx, Fy, Mx, My
	3 Abdomen Load Cells	Fy
Pelvis	Three Axis Lower Lumbar Load Cell	Fy, Fz, Mx
	Pubic Symphysis Load Cell	Fy
	Tri-axial Accelerometer Pack	Ax, Ay, Az
Legs	Six Axis Femur Load Cell	Fx, Fy, Fz, Mx My, Mz

IV.4. The dummy's conversion for right-sided impact

Conversion of ES2-re dummy from left to right side impacts involve the following actions:

- Head and neck: no change needed.
- Shoulder and arm:
  1) Upon removal of the arms, the left side shoulder cam and load cell assembly is flipped upside down and installed on the right side to the torso structure. The right shoulder cam is flipped upside down and installed on the left side to the torso structure.
  2) The thorax tilt sensor is moved from the left side mounting position to the right side.
- Thoracic rib structure
  1) To reverse the thorax for right side impact, it is necessary remove the back plate and the back plate load cell and rotate all three thorax rib modules upside down around the fore and aft axis of the dummy,
  2) Upon reattachment of the rib modules to the torso, reattach the load cell and the back plate with the beveled edge of the back plate facing the impact.
- Abdomen load cells
  The abdomen load cells are moved to the intended struck side replacing the load cell structural replacements that are attached to the mountings of the removed load cells.
- Leg load cells:
  If used, the femur load cells are moved to the struck side of the dummy.
- Polarities of all sensors of the involved parts need to be reconfigured according to SAE J211.

As stated in the European Union Side Impact Directive EU 96/27/EC, the ES-2 dummy is valid for both left and right-hand impact applications [6, Attachment 5]. There are no design changes in the ES-2re upgrade that would affect the applicability of the dummy in either right or left-hand impacts.

Chapter V Calibration/Certification tests

V.1 Component and subsystem/systems test description

One of the criteria for a dummy's acceptance is a demonstration that its components and/or subsystems are capable in well-defined tests (sometimes called calibration and sometimes certification) of responding to within established performance/biofidelity limits and with sufficient repeatability and reproducibility. Originally, the certification procedures were defined in the EEC document 96/27/EC pages 36 through 44 [6]. In 2001, the EEVC, upon an extensive evaluation of the EuroSID-1, recommended a number of adjustments in the certification procedures for the ES-2 dummy [2]. The recommended revisions have been mostly incorporated in the ES-2 User Manual of February 2002 [17], except for the pelvis impact velocity which was reduced from 6.3 m/s to 4.3 m/s.   The certification procedures used by the agency in the evaluation of the ES-2re dummies were based on specifications itemized in the EEVC Working Group 12 report of August 2001 and applicable recommended revisions [2]. Certification tests apply to the head, neck, shoulder, thorax, lumbar spine, abdomen and pelvis. The tests are grouped in two categories: component tests and full body tests. The thoracic rib modules were evaluated in three series of drop tests. Depending on the side to be impacted, the dummy's parts could be certified either for the left or right side impacts. Conversion procedure from left to right sided impact is provided in Chapter IV, Section 4.

V.2. Certification tests performed by the agency

Certification tests have been conducted by the agency at MGA Research Inc. with ES-2 dummies S/N 9 and S/N 10 initially, and ES-2re revisions of S/N 9 and S/N 10 subsequently. Additional calibration tests were performed by NHTSA's Vehicle Research and Test Center (VRTC) with newly purchased ES-2re dummies S/N 70 and S/N 71. The tests are described in the following paragraphs.

V.2.1. Component impact tests

- Head — A free-fall drop test from 200 mm height with the side of the head impacting a flat rigid surface
- Neck — An impact test at 3.4 m/s of the EUROSID-1 head form and the ES-2 neck mounted through an appropriate interface to the pendulum, causing lateral flexion, as well as rotation and translation of the neck
- Thorax — Impactor drop tests on each rib module by a mass of 7.78 kg from a height of 815, 459 and 204 mm
- Lumbar spine — An impact test with a pendulum at 6.05 m/s using the EUROSID-1 head form and ES-2 lumbar spine interface, causing lateral flexion, as well as rotation and translation of the lumbar spine

V.2.2 Local area tests performed on the fully assembled seated dummy

• Shoulder	1) Static shoulder resistance to ventral motion tests (not reported in this TR) 2) A lateral impact at 4.3 m/s on the upper arm pivot with a four wire suspended 23.4 kg mass impactor,
• Abdomen	A lateral impact at 4.0 m/s on the center of the abdomen with an eight wire suspended 23.4 kg mass impactor equipped with a 1.0 kg mass armrest-face,
• Pelvis	A lateral impact at 4.3 m/s on the H-point of the dummy with an eight wire suspended 23.4 kg mass impactor

V.3. Tests Results

Tables V-1 through V-36 list the calibration-certification tests performed at MGA Research Inc. with dummies S/N 9 and S/N 10. The tables describe the environment and equipment exposures, dummy's responses and the performance (calibration) specifications that are to be met. Tables V-1 through V-18 provide data for dummies S/N 9 (9 tests) and S/N 10 (7tests) in the ES-2re configuration and Tables V-19 through V-36 of the ES-2 S/N 9 and S/N 10 dummies (non-re configuration) each exposed to 8 repeat tests.

Additional 5 sets of repeat calibration tests were performed by NHTSA's Vehicle Research and Test Center (VRTC) with newly purchased ES-2 dummies S/N 70 and S/N 71 in the re configuration. Tables V-37 through V-43 provide data for these tests. Further details about the tests may be found in the VRTC Technical Report of March 2004 under the title "Evaluation of the EuroSID-2, Certification Test Repeatability and Reproducibility"[18].

Response averages, standard deviations, and coefficient of variation (CV) were computed for each specific test for all of the dummies to determine how well the dummy meets the calibration requirements and if any of the measured values would fall out of the acceptable specified performance range either by +/- one standard deviation from the combined average for a particular set of measurements or by individual responses. Since the dummies in the VRTC test series were new, they were also suitable for reproducibility assessment as discussed in Chapter IX.

As shown in tables V-1 through V-43 all average peak dummy responses fall well within the established performance specification ranges, except for the shoulder pendulum acceleration response in the VRTC test series (Table V-39) and one abdominal force response which was below the lower specified limit (Table V-41). In the shoulder certification tests at VRTC, the upper boundary of the calibration specification was exceeded in 8 out of 10 tests (Table V-39).

Data in Tables V-3, V-12, and V-39 indicate that averages of pendulum peak acceleration responses in the shoulder tests run between 9.68 g and 10.13 g in the MGA series and 10.8 g to 11.4 g. at VRTC. Tables V-21 and V-30 show for reference the responses of the ES-2 standard dummies. The data show that there is virtually no difference between ES-2re and ES-2 dummies. The data in both test series indicate that shoulder responses are clustered either at the higher end of or exceed somewhat the calibration corridor's upper limit of 10.5g.

Review of the design of the shoulder structure indicates that its reaction to pendulum impact, based on a circular motion of the clavicle with fulcrum at the spine, would be sensitive to small variations in the angle of impact on the dummy's arm. Accordingly, elevated variations in the impact response are to be expected. A similar observation on shoulder sensitivity was made in the EEVC report of 2001. It acknowledged 10% response variation on the impactor face in shoulder impacts.

VRTC compared the ES-2re dummy's shoulder response with the biomechanical data of the human shoulder developed by Bolte in Figure V-1. The ES-2re impact responses indicate excellent tracking of the cadaver response well past the maximum force response when the shoulder is impacted laterally at no angle. In as much as both sets of dummies' shoulders are bordering and/or exceeding the specified upper calibration limit, it is reasonable to suggest that the upper limit of the specified corridor be adjusted upwards to include the VRTC observed impact response.

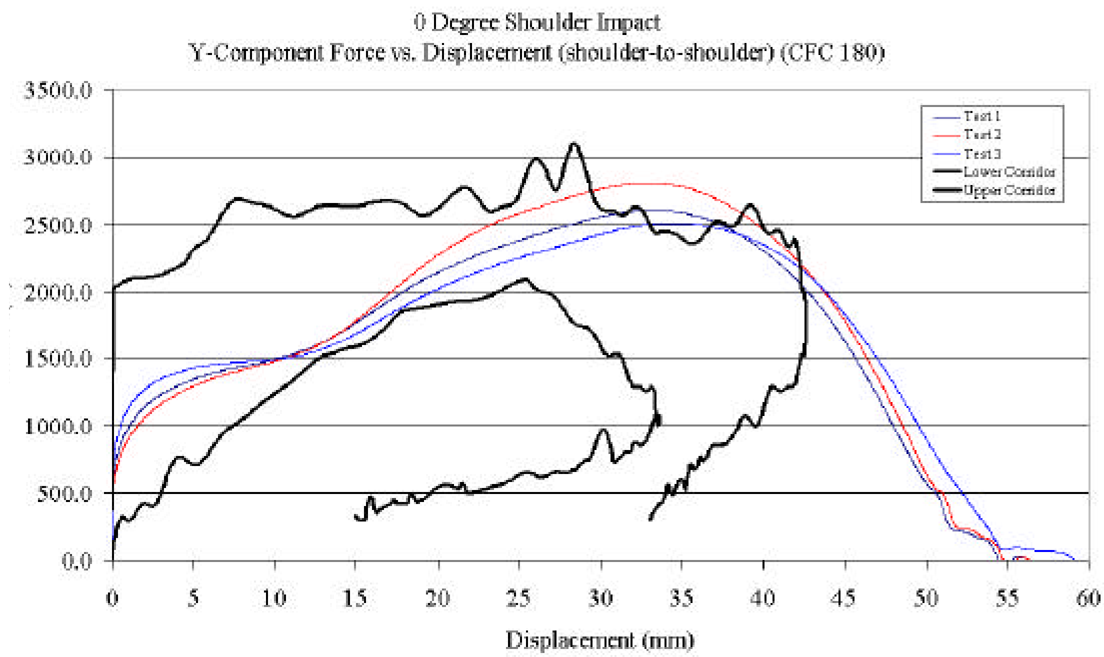

Figure V-1 Force vs. Displacement of the Shoulder Structure in Lateral Impact

Table V-41 shows that the abdominal response in test #3 of dummy S/N 70 was below the lower limit of the specification even though test #2, immediately before, and test # 4, immediately after, were well within the limits. Timing for the response was not significantly different for this test from the other two. Similarly, the responses measured by the pendulum-based accelerometers in tests #2, -3, and -4 were nearly identical. At this time we do not have an explanation for this single test aberration.

Both the MGA and the VRTC calibration-certification test series demonstrate excellent conformance to the specified calibration requirements and the suitability of the dummy for use in side impact testing. The repeatability and reproducibility aspects of these dummies are discussed in Chapter IX.

V.3.1 Data from Medical College of Wisconsin Component and Subsystem Tests

Table V-1. Head Drop Calibration Test (no. of tests = 9)

Occ. Type	S/N
ES-2RE	9

Head Drop				
Parameters	**Spec.**	**Avg.**	**Stdv.**	**CV (%)**
Temp (ºC)	18.0-22.0	21.02	0.50	2.36
Peak Res. Acc. Spec.	100-150 g's	138.78	5.59	4.02
Time of Max. Res. Acc.	ms	7.17		

Table V-2. Neck Pendulum Calibration Test (no. of tests = 9)

Occ. Type	S/N
ES-2RE	9

Neck Pendulum				
Parameters	**Spec.**	**Avg.**	**Stdv.**	**CV (%)**
Temp (ºC)	18.0 - 22.0	20.69	0.53	2.56
Pendulum Speed	3.3 - 3.5 (m/s)	3.39	0.03	0.98
Pendulum Deceleration (3 ms)	-0.25 - -0.53 (m/s)	-0.34	0.02	-4.65
Pendulum Deceleration (8 ms)	-1.59 - -2.04 (m/s)	-1.71	0.04	-2.49
Pendulum Deceleration (14 ms)	-3.20 - -3.85 (m/s)	-3.38	0.04	-1.07
Max. Flexion Angle	49.0 - 59.0 deg	57.82	1.46	2.53
Time of Max. Flexion Angle	54.0 - 66.0 ms	60.28	2.71	4.49
Max. Angle Theta (A)	32.0 - 37.0 deg	35.54	1.04	2.93
Time of Max. Theta (A)	53.0 - 63.0 ms	58.38	3.33	5.71
Max. Angle Theta (B)	30.10 - 32.60 deg	32.46	0.93	2.85
Time of Max. Theta (B)	54.0 - 64.0 ms	58.56	1.18	2.02

Table V-3 Shoulder Impact Calibration Test (no. of tests = 9)

Occ. Type	S/N
ES-2RE	9

Shoulder Impact				
Parameters	**Spec.**	**Avg.**	**Stdv.**	**CV (%)**
Temp (ºC)	18.0 - 22.0	20.62	0.74	3.57
Pendulum Speed	4.2 - 4.4 (m/s)	4.30	0.00	0.00
Max. Resultant Acceleration	7.5 - 10.5 g's	9.68	0.35	3.61
Time of Max. Pendulum Acc.	ms	12.79		

Table V-4 Upper Rib Calibration Test (no. of tests = 9)

Occ. Type	S/N
ES-2RE	9

Upper Rib				
Parameters	**Spec.**	**Avg.**	**Stdv.**	**CV (%)**
Temp (ºC)	18.0 - 22.0	20.97	0.38	1.83
Displacement a 2 m/s	23.5 - 27.5 mm	26.37	0.95	3.59
Displacement a 3 m/s	36.0 - 40.0 mm	39.18	0.85	2.17
Displacement a 4 m/s	46.0 - 51.0 mm	49.56	1.30	2.62

Table V-5 Middle Rib Calibration Test (no. of tests = 9)

Occ. Type	S/N
ES-2RE	9

Middle Rib				
Parameters	**Spec.**	**Avg.**	**Stdv.**	**CV (%)**
Temp (ºC)	18.0 - 22.0	20.97	0.38	1.83
Displacement a 2 m/s	23.5 - 27.5 mm	25.80	0.80	3.09
Displacement a 3 m/s	36.0 - 40.0 mm	37.92	1.14	3.01
Displacement a 4 m/s	46.0 - 51.0 mm	49.06	1.28	2.61

Table V-6. Lower Rib Calibration Test (no. of tests = 9)

Occ. Type	S/N
ES-2RE	9

Lower Rib				
Parameters	**Spec.**	**Avg.**	**Stdv.**	**CV (%)**
Temp (ºC)	18.0 - 22.0	20.97	0.38	1.83
Displacement a 2 m/s	23.5 - 27.5 mm	25.22	0.87	3.43
Displacement a 3 m/s	36.0 - 40.0 mm	37.37	0.81	2.18
Displacement a 4 m/s	46.0 - 51.0 mm	48.54	0.90	1.86

Table V-7. Abdomen Calibration Test (no. of tests = 9)

Occ. Type	S/N
ES-2RE	9

Abdomen				
Parameters	**Spec.**	**Avg.**	**Stdv.**	**CV (%)**
Temp (ºC)	18.0 - 22.0	20.62	0.65	3.13
Probe Speed (m/s)	3.90 - 4.10	3.99	0.05	1.23
Max. Impact Force	4.00 - 4.80 kN	4.40	0.13	3.04
Time of Max. Force	10.60 - 13.00 ms	10.83	0.17	1.60
Max. Total Abdomen Force	2.20 - 2.70 kN	2.36	0.08	3.37
Time of Max. Total Ab. Force	10.00 - 12.30 ms	10.33	0.20	1.94

Table V-8. Lumbar Spine Calibration Test (no. of tests =9)

Occ. Type	S/N
ES-2RE	9

Lumbar Spine				
Parameters	**Spec.**	**Avg.**	**Stdv.**	**CV (%)**
Temp (ºC)	18.0 - 22.0	20.66	0.58	2.82
Pendulum Speed	5.95 - 6.15	6.05	0.04	0.71
Pendulum Deceleration (10 ms)	-2.46- -1.59 (m/s)	-1.94	0.06	-3.03
Pendulum Deceleration (20 ms)	-5.25 - -4.07 (m/s)	-4.40	0.13	-2.87
Pendulum Deceleration (25 ms)	-6.64 - -5.30 (m/s)	-5.52	0.16	-2.86
Pendulum Deceleration (30 ms)	>= -6.5 (m/s)	-6.20	0.06	-0.99
Max. Flexion Angle	45.0 - 55.0 deg	50.73	2.13	4.20
Time of Max. Flexion Angle	39.0 - 53.0 ms	46.33	1.54	3.33
Max. Angle Theta (A)	31.0 - 35.0 deg	32.61	1.21	3.70
Time of Max. Theta (A)	44.0 - 52.0 ms	45.88	1.42	3.10
Max. Angle Theta (B)	28.88 - 31.38 deg	29.20	1.07	3.65
Time of Max. Theta (B)	44.0 - 52.0 ms	46.24	1.78	3.86

Table V-9. Pelvis Calibration Test (no. of tests = 9)

Occ. Type	S/N
ES-2RE	9

Pelvis				
Parameters	**Spec.**	**Avg.**	**Stdv.**	**CV (%)**
Temp (ºC)	18.0 - 22.0	20.51	0.69	3.37
Pendulum Speed	4.20 - 4.40 m/s	4.30	0.02	0.44
Max. Impact Force	4.40 - 5.40 kN	4.65	0.16	3.45
Time of Max. Force	10.30 - 15.50 ms	14.40	0.70	4.87
Max. Pubic Force	1.04 - 1.64 kN	1.31	0.06	4.90
Time of Max.Pubic Force	9.90 - 15.90 ms	14.39	0.55	3.83

Table V-10. Head Drop Calibration Test (no. of tests = 7)

Occ. Type	S/N
ES-2RE	10

Head Drop				
Parameters	**Spec.**	**Avg.**	**Stdv.**	**CV (%)**
Temp (ºC)	18.0-22.0	21.04	0.59	2.81
Peak Res. Acc. Spec.	100-150 g's	139.86	6.26	4.47
Time of Max. Res. Acc.	ms	8.21		

Table V-11. Neck Pendulum Calibration Test (no. of tests = 7)

Occ. Type	S/N
ES-2RE	10

Neck Pendulum				
Parameters	**Spec.**	**Avg.**	**Stdv.**	**CV (%)**
Temp (ºC)	18.0 - 22.0	20.71	0.57	2.74
Pendulum Speed	3.3 - 3.5 (m/s)	3.40	0.00	0.00
Pendulum Deceleration (3 ms)	-0.25 - -0.53 (m/s)	-0.33	0.01	-4.29
Pendulum Deceleration (8 ms)	-1.59 - -2.04 (m/s)	-1.69	0.06	-3.68
Pendulum Deceleration (14 ms)	-3.20 - -3.85 (m/s)	-3.36	0.06	-1.90
Max. Flexion Angle	49.0 - 59.0 deg	57.36	0.70	1.22
Time of Max. Flexion Angle	54.0 - 66.0 ms	58.73	1.56	2.66
Max. Angle Theta (A)	32.0 - 37.0 deg	35.29	0.62	1.77
Time of Max. Theta (A)	53.0 - 63.0 ms	56.74	2.09	3.68
Max. Angle Theta (B)	30.10 - 32.60 deg	31.99	0.67	2.10
Time of Max. Theta (B)	54.0 - 64.0 ms	58.90	0.58	0.98

Table V-12 Shoulder Impact Calibration Test (no. of tests = 7)

Occ. Type	S/N
ES-2RE	10

Shoulder Impact				
Parameters	**Spec.**	**Avg.**	**Stdv.**	**CV (%)**
Temp (ºC)	18.0 - 22.0	20.93	0.80	3.82
Pendulum Speed	4.2 - 4.4 (m/s)	4.29	0.04	0.88
Max. Resultant Acceleration	7.5 - 10.5 g's	10.13	0.29	2.83
Time of Max. Pendulum Acc.	ms	14.54		

Table V-13 Upper Rib Calibration Test (no. of tests = 7)

Occ. Type	S/N
ES-2RE	10

Upper Rib				
Parameters	**Spec.**	**Avg.**	**Stdv.**	**CV (%)**
Temp (ºC)	18.0 - 22.0	20.99	0.48	2.28
Displacement a 2 m/s	23.5 - 27.5 mm	25.96	0.77	2.97
Displacement a 3 m/s	36.0 - 40.0 mm	38.84	0.82	2.10
Displacement a 4 m/s	46.0 - 51.0 mm	49.80	0.93	1.86

Table V-14 Middle Rib Calibration Test (no. of tests = 7)

Occ. Type	S/N
ES-2RE	10

Middle Rib				
Parameters	**Spec.**	**Avg.**	**Stdv.**	**CV (%)**
Temp (ºC)	18.0 - 22.0	20.99	0.48	2.28
Displacement a 2 m/s	23.5 - 27.5 mm	25.33	0.72	2.84
Displacement a 3 m/s	36.0 - 40.0 mm	38.20	0.71	1.85
Displacement a 4 m/s	46.0 - 51.0 mm	49.47	0.72	1.46

Table V-15. Lower Rib Calibration Test (no. of tests = 7)

Occ. Type	S/N
ES-2RE	10

Lower Rib				
Parameters	**Spec.**	**Avg.**	**Stdv.**	**CV (%)**
Temp (ºC)	18.0 - 22.0	20.99	0.48	2.28
Displacement a 2 m/s	23.5 - 27.5 mm	25.93	0.74	2.85
Displacement a 3 m/s	36.0 - 40.0 mm	38.49	0.56	1.46
Displacement a 4 m/s	46.0 - 51.0 mm	50.11	0.37	0.74

Table V-16. Abdomen Calibration Test (no. of tests = 7)

Occ. Type	S/N
ES-2RE	10

Abdomen				
Parameters	**Spec.**	**Avg.**	**Stdv.**	**CV (%)**
Temp (ºC)	18.0 - 22.0	20.94	0.76	3.61
Probe Speed (m/s)	3.90 - 4.10	4.00	0.05	1.27
Max. Impact Force	4.00 - 4.80 kN	4.56	0.17	3.66
Time of Max. Force	10.60 - 13.00 ms	11.44	0.79	6.90
Max. Total Abdomen Force	2.20 - 2.70 kN	2.48	0.07	2.66
Time of Max. Total Ab. Force	10.00 - 12.30 ms	11.40	0.63	5.50

Table V-17. Lumbar Spine Calibration Test (no. of tests = 7)

Occ. Type	S/N
ES-2RE	10

Lumbar Spine				
Parameters	**Spec.**	**Avg.**	**Stdv.**	**CV (%)**
Temp (ºC)	18.0 - 22.0	20.79	0.55	2.66
Pendulum Speed	5.95 - 6.15	6.07	0.05	0.83
Pendulum Deceleration (10 ms)	-2.46- -1.59 (m/s)	-1.92	0.06	-3.30
Pendulum Deceleration (20 ms)	-5.25 - -4.07 (m/s)	-4.34	0.15	-3.40
Pendulum Deceleration (25 ms)	-6.64 - -5.30 (m/s)	-5.46	0.13	-2.30
Pendulum Deceleration (30 ms)	>= -6.5 (m/s)	-6.14	0.09	-1.46
Max. Flexion Angle	45.0 - 55.0 deg	51.00	2.53	4.96
Time of Max. Flexion Angle	39.0 - 53.0 ms	47.59	2.09	4.38
Max. Angle Theta (A)	31.0 - 35.0 deg	32.71	1.19	3.64
Time of Max. Theta (A)	44.0 - 52.0 ms	47.40	1.94	4.09
Max. Angle Theta (B)	28.88 - 31.38 deg	29.68	1.21	4.06
Time of Max. Theta (B)	44.0 - 52.0 ms	46.96	1.64	3.49

Table V-18. Pelvis Calibration Test (no. of tests = 7)

Occ. Type	S/N
ES-2RE	10

Pelvis				
Parameters	**Spec.**	**Avg.**	**Stdv.**	**CV (%)**
Temp (ºC)	18.0 - 22.0	20.94	0.78	3.74
Pendulum Speed	4.20 - 4.40 m/s	4.30	0.02	0.44
Max. Impact Force	4.40 - 5.40 kN	4.94	0.19	3.93
Time of Max. Force	10.30 - 15.50 ms	13.40	0.61	4.58
Max. Pubic Force	1.04 - 1.64 kN	1.40	0.09	6.24
Time of Max.Pubic Force	9.90 - 15.90 ms	13.66	1.30	9.50

Table V-19. Head Drop Calibration Test (no. of tests = 8)

Occ. Type	S/N
ES-2	9

Head Drop				
Parameters	**Spec.**	**Avg.**	**Stdv.**	**CV (%)**
Temp (ºC)	18.0-22.0	21.16	0.47	2.22
Peak Res. Acc. Spec.	100-150 g's	142.00	5.50	3.88
Time of Max. Res. Acc.	ms	24.14		

Table V-20 Neck Pendulum Calibration Test (no. of tests = 8)

Occ. Type	S/N	Neck Pendulum				
ES-2	9	**Parameters**	**Spec.**	**Avg.**	**Stdv.**	**CV (%)**
		Temp (ºC)	18.0 - 22.0	21.21	0.46	2.17
		Pendulum Speed	3.3 - 3.5 (m/s)	3.40	0.00	0.00
		Pendulum Deceleration (3 ms)	-0.25 - -0.53 (m/s)	-0.33	0.01	-4.24
		Pendulum Deceleration (8 ms)	-1.59 - -2.04 (m/s)	-1.70	0.02	-0.91
		Pendulum Deceleration (14 ms)	-3.20 - -3.85 (m/s)	-3.34	0.02	-0.72
		Max. Flexion Angle	49.0 - 59.0 deg	54.99	1.18	2.14
		Time of Max. Flexion Angle	54.0 - 66.0 ms	58.44	0.85	1.45
		Max. Angle Theta (A)	32.0 - 37.0 deg	33.79	0.76	2.25
		Time of Max. Theta (A)	53.0 - 63.0 ms	57.95	0.72	1.24
		Max. Angle Theta (B)	30.10 - 32.60 deg	30.20	0.60	1.99
		Time of Max. Theta (B)	54.0 - 64.0 ms	57.41	1.16	2.03

Table V-21. Shoulder Impact Calibration Test (no. of tests = 8)

Occ. Type	S/N	Shoulder Impact				
ES-2	9	**Parameters**	**Spec.**	**Avg.**	**Stdv.**	**CV (%)**
		Temp (ºC)	18.0 - 22.0	21.21	0.37	1.75
		Pendulum Speed	4.2 - 4.4 (m/s)	4.30	0.00	0.00
		Max. Resultant Acceleration	7.5 - 10.5 g's	9.55	0.57	6.00
		Time of Max. Pendulum Acc.	ms	25.45		

Table V-22. Upper Rib Calibration Test (no. of tests = 8)

Occ. Type	S/N	Upper Rib				
ES-2	9	**Parameters**	**Spec.**	**Avg.**	**Stdv.**	**CV (%)**
		Temp (ºC)	18.0 - 22.0	21.01	0.61	2.88
		Displacement a 2 m/s	23.5 - 27.5 mm	25.69	0.48	1.88
		Displacement a 3 m/s	36.0 - 40.0 mm	38.98	0.54	1.38
		Displacement a 4 m/s	46.0 - 51.0 mm	50.13	0.53	1.06

Table V-23. Middle Rib Calibration Test (no. of tests = 8)

Occ. Type	S/N	Middle Rib				
ES-2	9	**Parameters**	**Spec.**	**Avg.**	**Stdv.**	**CV (%)**
		Temp (ºC)	18.0 - 22.0	21.10	0.53	2.53
		Displacement a 2 m/s	23.5 - 27.5 mm	26.33	0.69	2.64
		Displacement a 3 m/s	36.0 - 40.0 mm	39.26	0.40	1.02
		Displacement a 4 m/s	46.0 - 51.0 mm	50.44	0.26	0.51

Table V-24. Lower Rib Calibration Test (no. of tests = 8)

Occ. Type	S/N
ES-2	9

Lower Rib				
Parameters	**Spec.**	**Avg.**	**Stdv.**	**CV (%)**
Temp (ºC)	18.0 - 22.0	21.10	0.53	2.53
Displacement a 2 m/s	23.5 - 27.5 mm	25.89	0.87	3.38
Displacement a 3 m/s	36.0 - 40.0 mm	38.93	0.62	1.58
Displacement a 4 m/s	46.0 - 51.0 mm	50.11	0.81	1.62

Table V-25 Abdomen Calibration Test (no. of tests = 8)

Occ. Type	S/N
ES-2	9

Abdomen				
Parameters	**Spec.**	**Avg.**	**Stdv.**	**CV (%)**
Temp (ºC)	18.0 - 22.0	21.34	0.37	1.75
Probe Speed (m/s)	3.90 - 4.10	3.99	0.02	0.51
Max. Impact Force	4.00 - 4.80 kN	4.74	0.05	1.01
Time of Max. Force	10.60 - 13.00 ms	10.98	0.35	3.22
Max. Total Abdomen Force	2.20 - 2.70 kN	2.34	0.10	4.38
Time of Max. Total Ab. Force	10.00 - 12.30 ms	10.61	0.37	3.51

Table V-26 Lumbar Spine Calibration Test (no. of tests = 8)

Occ. Type	S/N
ES-2	9

Lumbar Spine				
Parameters	**Spec.**	**Avg.**	**Stdv.**	**CV (%)**
Temp (ºC)	18.0 - 22.0	21.41	0.36	1.68
Pendulum Speed	5.95 - 6.15	6.07	0.05	0.82
Pendulum Deceleration (10 ms)	-2.46- -1.59 (m/s)	-1.98	0.10	-4.96
Pendulum Deceleration (20 ms)	-5.25 - -4.07 (m/s)	-4.51	0.21	-4.76
Pendulum Deceleration (25 ms)	-6.64 - -5.30 (m/s)	-5.60	0.26	-4.62
Pendulum Deceleration (30 ms)	>= -6.5 (m/s)	-6.11	0.08	-1.26
Max. Flexion Angle	45.0 - 55.0 deg	50.61	1.75	3.46
Time of Max. Flexion Angle	39.0 - 53.0 ms	45.36	1.02	2.26
Max. Angle Theta (A)	31.0 - 35.0 deg	32.29	0.96	2.98
Time of Max. Theta (A)	44.0 - 52.0 ms	45.39	1.22	2.68
Max. Angle Theta (B)	28.88 - 31.38 deg	28.68	0.94	3.27
Time of Max. Theta (B)	44.0 - 52.0 ms	46.05	1.41	3.06

Table V-27 Pelvis Calibration Test (no. of tests = 8)

Occ. Type	S/N
ES-2	9

Pelvis				
Parameters	**Spec.**	**Avg.**	**Stdv.**	**CV (%)**
Temp (ºC)	18.0 - 22.0	21.26	0.39	1.83
Pendulum Speed	4.20 - 4.40 m/s	6.24	0.03	0.45
Max. Impact Force	4.40 - 5.40 kN	10.92	0.39	3.57
Time of Max. Force	10.30 - 15.50 ms	11.25	0.26	2.33
Max. Pubic Force	1.04 - 1.64 kN	3.27	0.09	2.63
Time of Max.Pubic Force	9.90 - 15.90 ms	11.51	0.35	3.02

Table V-28 Head Drop Calibration Test (no. of tests = 8)

Occ. Type	S/N	Head Drop				
		Parameters	Spec.	Avg.	Stdv.	CV (%)
ES-2	10	Temp (ºC)	18.0-22.0	21.1	0.40	1.88
		Peak Res. Acc. Spec.	100-150 g's	142.00	4.00	2.82
		Time of Max. Res. Acc.	ms	25.51		

Table V-29. Neck Pendulum Calibration Test (no. of tests = 8)

Occ. Type	S/N	Neck Pendulum				
		Parameters	Spec.	Avg.	Stdv.	CV (%)
ES-2	10	Temp (ºC)	18.0 - 22.0	21.28	0.46	2.14
		Pendulum Speed	3.3 - 3.5 (m/s)	3.38	0.05	1.37
		Pendulum Deceleration (3 ms)	-0.25 - -0.53 (m/s)	-0.33	0.01	-3.25
		Pendulum Deceleration (8 ms)	-1.59 - -2.04 (m/s)	-1.71	0.04	-2.58
		Pendulum Deceleration (14 ms)	-3.20 - -3.85 (m/s)	-3.35	0.05	-1.36
		Max. Flexion Angle	49.0 - 59.0 deg	56.28	1.66	2.95
		Time of Max. Flexion Angle	54.0 - 66.0 ms	58.53	2.20	3.75
		Max. Angle Theta (A)	32.0 - 37.0 deg	34.43	0.85	2.46
		Time of Max. Theta (A)	53.0 - 63.0 ms	59.39	1.35	2.27
		Max. Angle Theta (B)	30.10 - 32.60 deg	31.03	0.65	2.09
		Time of Max. Theta (B)	54.0 - 64.0 ms	57.95	2.56	4.41

Table V-30 Shoulder Impact Calibration Test (no. of tests = 8)

Occ. Type	S/N	Shoulder Impact				
		Parameters	Spec.	Avg.	Stdv.	CV (%)
ES-2	10	Temp (ºC)	18.0 - 22.0	21.24	0.48	2.28
		Pendulum Speed	4.2 - 4.4 (m/s)	4.30	0.00	0.00
		Max. Resultant Acceleration	7.5 - 10.5 g's	9.89	0.56	5.63
		Time of Max. Pendulum Acc.	ms	24.64		

Table V-31. Upper Rib Calibration Test (no. of tests = 8)

Occ. Type	S/N	Upper Rib				
		Parameters	Spec.	Avg.	Stdv.	CV (%)
ES-2	10	Temp (ºC)	18.0 - 22.0	21.21	0.56	2.65
		Displacement a 2 m/s	23.5 - 27.5 mm	25.79	0.87	3.36
		Displacement a 3 m/s	36.0 - 40.0 mm	38.49	0.49	1.26
		Displacement a 4 m/s	46.0 - 51.0 mm	48.81	0.85	1.75

Table V-32. Middle Rib Calibration Test (no. of tests = 8)

Occ. Type	S/N	Middle Rib				
		Parameters	Spec.	Avg.	Stdv.	CV (%)
ES-2	10	Temp (ºC)	18.0 - 22.0	21.23	0.57	2.66
		Displacement a 2 m/s	23.5 - 27.5 mm	25.44	0.66	2.61
		Displacement a 3 m/s	36.0 - 40.0 mm	37.94	0.53	1.39
		Displacement a 4 m/s	46.0 - 51.0 mm	49.18	0.79	1.61

Occ. Type	S/N
ES-2	10

Table V-33. Lower Rib Calibration Test (no. of tests = 8)

Lower Rib				
Parameters	**Spec.**	**Avg.**	**Stdv.**	**CV (%)**
Temp (ºC)	18.0 - 22.0	21.24	0.57	2.69
Displacement a 2 m/s	23.5 - 27.5 mm	24.85	0.56	2.25
Displacement a 3 m/s	36.0 - 40.0 mm	37.81	0.96	2.55
Displacement a 4 m/s	46.0 - 51.0 mm	49.26	0.66	1.34

Occ. Type	S/N
ES-2	10

Table V-34 Abdomen Calibration Test (no. of tests = 8)

Abdomen				
Parameters	**Spec.**	**Avg.**	**Stdv.**	**CV (%)**
Temp (ºC)	18.0 - 22.0	21.45	0.42	1.95
Probe Speed (m/s)	3.90 - 4.10	3.99	0.02	0.51
Max. Impact Force	4.00 - 4.80 kN	4.68	0.09	1.91
Time of Max. Force	10.60 - 13.00 ms	12.14	0.50	4.11
Max. Total Abdomen Force	2.20 - 2.70 kN	2.27	0.07	2.97
Time of Max. Total Ab. Force	10.00 - 12.30 ms	11.79	0.31	2.62

Occ. Type	S/N
ES-2	10

Table V-35 Lumbar Spine Calibration Test (no. of tests = 8)

Lumbar Spine				
Parameters	**Spec.**	**Avg.**	**Stdv.**	**CV (%)**
Temp (ºC)	18.0 - 22.0	21.24	0.45	2.13
Pendulum Speed	5.95 - 6.15	6.07	0.05	0.74
Pendulum Deceleration (10 ms)	-2.46- -1.59 (m/s)	-2.00	0.08	-3.77
Pendulum Deceleration (20 ms)	-5.25 - -4.07 (m/s)	-4.54	0.20	-4.41
Pendulum Deceleration (25 ms)	-6.64 - -5.30 (m/s)	-5.62	0.24	-4.21
Pendulum Deceleration (30 ms)	>= -6.5 (m/s)	-6.15	0.06	-0.91
Max. Flexion Angle	45.0 - 55.0 deg	49.95	1.66	3.33
Time of Max. Flexion Angle	39.0 - 53.0 ms	44.90	1.36	3.04
Max. Angle Theta (A)	31.0 - 35.0 deg	32.11	0.58	1.80
Time of Max. Theta (A)	44.0 - 52.0 ms	45.48	1.49	3.29
Max. Angle Theta (B)	28.88 - 31.38 deg	28.58	0.77	2.70
Time of Max. Theta (B)	44.0 - 52.0 ms	47.41	1.36	2.86

Occ. Type	S/N
ES-2	10

Table V-36 Pelvis Calibration Test (no. of tests = 8)

Pelvis				
Parameters	**Spec.**	**Avg.**	**Stdv.**	**CV (%)**
Temp (ºC)	18.0 - 22.0	21.45	0.42	1.95
Pendulum Speed	4.20 - 4.40 m/s	6.23	0.02	0.39
Max. Impact Force	4.40 - 5.40 kN	10.98	0.40	3.68
Time of Max. Force	10.30 - 15.50 ms	11.45	0.27	2.38
Max. Pubic Force	1.04 - 1.64 kN	3.26	0.10	3.03
Time of Max.Pubic Force	9.90 - 15.90 ms	11.65	0.24	2.10

V.3.2. Results from VRTC Component and Subsystem Tests

Table V-37. Head Certification Test Results

Dummy No./ Test No.	**Peak Resultant Acceleration (g)**
Specification	100 - 150
070/1	148.8
070/2	145.0
070/3	146.7
070/4	146.0
070/5	144.9
071/1	133.0
071/2	131.0
071/3	135.5
071/4	130.4
071/5	131.4
Dummy 070	
Mean	**146.3**
Standard Deviation	**1.6**
CV (%)	**1.1%**
Dummy 071	
Mean	**132.3**
Standard Deviation	**2.1**
CV (%)	**1.6%**
Both Dummies	
Mean	**139.3**
Standard Deviation	**7.6**
CV (%)	**5.4%**

Table V-38. Neck Certification Test Results

Dummy No./ Test No.	Pendulum Velocity (m/s)	Peak Flexion Angle (deg)	Time of Peak Flexion Angle (ms)	Peak A Angle (deg)	Time of Peak A Angle (ms)	Peak B Angle (deg)	Time of Peak B Angle (ms)
Specification	3.30-3.50	49.0-59.0	54.0-66.0	32.0-37.0	53.0-63.0	.81*(A)+3.0 ±1.25	54.0-64.0
070/1	3.46	55.6	57.34	35.5	56.25	32.6	55.34
070/2	3.38	54.5	57.70	35.0	55.98	32.1	57.70
070/3	3.38	55.2	58.54	35.4	56.72	32.5	57.24
070/4	3.39	55.3	60.22	35.1	53.74	32.2	57.18
070/5	3.39	54.6	56.68	35.3	54.82	32.2	56.56
071/1	3.39	54.1	57.80	34.5	55.92	31.7	54.98
071/2	3.38	54.4	57.56	34.7	54.60	31.9	**53.02**
071/3	3.38	54.8	58.14	35.0	55.94	32.0	56.74
071/4	3.38	54.3	59.36	34.6	54.50	31.8	55.46
071/5	3.39	54.6	55.10	34.9	54.58	32.0	56.22
Dummy 070							
Mean	**3.40**	**55.0**	**58.10**	**35.2**	**55.50**	**32.3**	**56.80**
Standard Deviation	**0.03**	**0.5**	**1.36**	**0.2**	**1.21**	**0.2**	**0.91**
CV (%)	**1.0%**	**0.9%**	**2.3%**	**0.7%**	**2.2%**	**0.7%**	**1.6%**
Dummy 071							
Mean	**3.38**	**54.4**	**57.59**	**34.8**	**55.11**	**31.9**	**55.28**
Standard Deviation	**0.01**	**0.3**	**1.56**	**0.2**	**0.75**	**0.1**	**1.44**
CV (%)	**0.2%**	**0.5%**	**2.7%**	**0.5%**	**1.4%**	**0.5%**	**2.6%**
Both Dummies							
Mean	**3.39**	**54.7**	**57.84**	**35.0**	**55.31**	**32.1**	**56.04**
Standard Deviation	**0.02**	**0.5**	**1.40**	**0.3**	**0.97**	**0.3**	**1.39**
CV (%)	**0.7%**	**0.9%**	**2.4%**	**0.9%**	**1.8%**	**0.9%**	**2.5%**

Table V-39. Shoulder Certification Test Results

Dummy No./ Test No.	Impactor Velocity (m/sec)	Peak Impactor Acceleration (g)
Specification	4.20-4.40	7.5-10.5
070/1	4.35	**11.2**
070/2	4.31	**11.4**
070/3	4.32	**11.2**
070/4	4.32	**11.2**
070/5	4.35	**11.9**
071/1	4.31	**11.1**
071/2	4.31	**10.6**
071/3	4.32	9.7
071/4	4.31	**12.4**
071/5	4.32	10.2
Dummy 070		
Mean	**4.33**	**11.4**
Standard Deviation	**0.02**	**0.3**
CV (%)	**0.4%**	**2.7%**
Dummy 071		
Mean	**4.31**	**10.8**
Standard Deviation	**0.01**	**1.0**
CV (%)	**0.1%**	**9.3%**
Both Dummies		
Mean	**4.32**	**11.1**
Standard Deviation	**0.02**	**0.8**
CV (%)	**0.4%**	**6.9%**

Table V-40-1. Upper Rib Module* Certification Test Results

Dummy No./ Test No.	Deflection (mm) 815 mm Drop Height	Deflection (mm) 459 mm Drop Height	Deflection (mm) 204 mm Drop Height
Specification	46.0-51.0	36.0-40.0	23.5-27.5
070/1	47.9	36.2	24.0
070/2	47.6		
070/3	47.3		
070/4	48.4		
070/5	46.4		
071/1	49.8	37.9	25.4
071/2	49.8		
071/3	46.1		
071/4	50.1		
Dummy 070			
Mean	**47.5**		
Standard Deviation	**0.7**		
CV (%)	**1.5%**		
Dummy 071			
Mean	**48.9**		
Standard Deviation	**1.9**		
CV (%)	**3.9%**		
Both Dummies			
Mean	**48.2**		
Standard Deviation	**1.5**		
CV (%)	**3.1%**		

***Thorax (Rib Modules)**

The test procedure requires each individual rib module to be tested at three impact energies. To assess repeatability and reproducibility, only the 815 mm drop tests were repeated since that condition produces the greatest deflection. For each rib module (upper, middle and lower), five 815 mm drop impacts were conducted for dummy 070 and four tests were conducted for dummy 071. The fifth test for dummy 071 was inadvertently not performed. Only one test per rib module was performed at the two lower drop heights for each dummy.

Table V-40-2 Middle Rib Module* Certification Test Results

Dummy No./ Test No.	Deflection (mm) 815 mm Drop Height	Deflection (mm) 459 mm Drop Height	Deflection (mm) 204 mm Drop Height
Specification	46.0-51.0	36.0-40.0	23.5-27.5
070/1	49.6	37.5	25.2
070/2	49.3		
070/3	49.1		
070/4	49.2		
070/5	49.3		
071/1	49.1	37.3	24.9
071/2	49.2		
071/3	49.4		
071/4	49.3		
Dummy 070			
Mean	**49.3**		
Standard Deviation	**0.2**		
CV (%)	**0.3%**		
Dummy 071			
Mean	**49.2**		
Standard Deviation	**0.1**		
CV (%)	**0.3%**		
Both Dummies			
Mean	**49.3**		
Standard Deviation	**0.1**		
CV (%)	**0.3%**		

Thorax (Rib Modules)

The test procedure requires each individual rib module to be tested at three impact energies. To assess repeatability and reproducibility, only the 815 mm drop tests were repeated since that condition produces the greatest deflection. For each rib module (upper, middle and lower), five 815 mm drop impacts were conducted for dummy 070 and four tests were conducted for dummy 071. The fifth test for dummy 071 was inadvertently not performed. Only one test per rib module was performed at the two lower drop heights for each dummy.

Table V-40-3 Lower Rib Module* Certification Test Results

Dummy No./ Test No.	Deflection (mm) 815 mm Drop Height	Deflection (mm) 459 mm Drop Height	Deflection (mm) 204 mm Drop Height
Specification	46.0-51.0	36.0-40.0	23.5-27.5
070/1	49.2	37.0	24.8
070/2	49.8		
070/3	49.5		
070/4	49.6		
070/5	49.5		
071/1	49.2	37.7	24.4
071/2	49.2		
071/3	49.2		
071/4	49.2		
Dummy 070			
Mean	**49.5**		
Standard Deviation	**0.2**		
CV (%)	**0.4%**		
Dummy 071			
Mean	**49.2**		
Standard Deviation	**0.0**		
CV (%)	**0.0%**		
Both Dummies			
Mean	**49.4**		
Standard Deviation	**0.2**		
CV (%)	**0.5%**		

***Thorax (Rib Modules)**

The test procedure requires each individual rib module to be tested at three impact energies. To assess repeatability and reproducibility, only the 815 mm drop tests were repeated since that condition produces the greatest deflection. For each rib module (upper, middle and lower), five 815 mm drop impacts were conducted for dummy 070 and four tests were conducted for dummy 071. The fifth test for dummy 071 was inadvertently not performed. Only one test per rib module was performed at the two lower drop heights for each dummy.

Table V-41 Abdomen Certification Test Results

Dummy No./ Test No.	Impactor Velocity (m/s)	Max. Impactor Force (N)	Time of Max. Impactor Force (ms)	Max. Abdomen Force (N)	Time of Max. Abdomen Force (ms)
Specification	3.9-4.1	4000-4800	10.60-13.00	2200-2700	10.00-12.30
070/1	4.04	4580	12.68	2428	12.10
070/2	4.03	4781	12.64	2276	11.92
070/3	4.03	4627	12.54	**2002**	11.56
070/4	4.02	4796	12.48	2239	11.80
070/5	4.02	4777	12.50	2294	11.90
071/1	4.10	4736	12.36	2501	12.06
071/2	3.99	4826	12.58	2368	12.14
071/3	3.97	4787	12.52	2453	12.20
071/4	4.02	4636	12.22	2490	11.98
071/5	3.99	4611	12.52	2287	11.90
Dummy 070					
Mean	**4.03**	**4712**	**12.57**	**2248**	**11.86**
Standard Deviation	**0.01**	**101**	**0.09**	**155**	**0.20**
CV (%)	**0.2%**	**2.1%**	**0.7%**	**6.9%**	**1.7%**
Dummy 071					
Mean	**4.01**	**4719**	**12.44**	**2420**	**12.06**
Standard Deviation	**0.05**	**93**	**0.15**	**91**	**0.12**
CV (%)	**1.3%**	**2.0%**	**1.2%**	**3.8%**	**1.0%**
Both Dummies					
Mean	**4.02**	**4716**	**12.50**	**2334**	**11.96**
Standard Deviation	**0.04**	**92**	**0.13**	**150**	**0.19**
CV (%)	**0.9%**	**1.9%**	**1.1%**	**6.4%**	**1.6%**

Table V-42 Lumbar Spine Certification Test Results

Dummy No./ Test No.	Pendulum Velocity (m/s)	Peak Flexion Angle (deg)	Time of Peak Flexion Angle (ms)	Peak A Angle (deg)	Time of Peak A Angle (ms)	Peak B Angle (deg)	Time of Peak B Angle (ms)
Specification	5.95-6.15	45.0-55.0	39.0-53.0	31.0-35.0	44.0-52.0	.8*(A)+3.25 ±1.25	44.0-52.0
070/1	6.03	48.4	44.84	32.4	45.10	29.9	44.46
070/2	6.05	47.4	46.22	31.7	45.92	29.7	45.74
070/3	6.03	48.1	46.08	32.4	45.92	29.8	44.74
070/4	6.03	48.0	46.84	32.2	46.76	29.6	46.38
070/5	6.05	48.2	46.60	32.4	46.62	29.7	45.90
071/1	6.03	47.8	46.86	32.5	47.04	29.6	45.58
071/2	6.03	47.4	44.72	32.2	44.72	29.3	44.88
071/3	6.03	48.1	45.90	32.7	47.16	29.6	45.32
071/4	6.03	48.8	45.70	33.2	45.72	30.1	45.28
071/5	6.03	49.0	46.80	33.4	46.78	30.2	44.90
Dummy 070							
Mean	**6.04**	**48.0**	**46.12**	**32.2**	**46.06**	**29.7**	**45.44**
Standard Deviation	**0.01**	**0.4**	**0.77**	**0.3**	**0.66**	**0.1**	**0.81**
CV (%)	**0.2%**	**0.8%**	**1.7%**	**0.9%**	**1.4%**	**0.3%**	**1.8%**
Dummy 071							
Mean	**6.03**	**48.2**	**46.00**	**32.8**	**46.28**	**29.7**	**45.19**
Standard Deviation	**0.00**	**0.7**	**0.88**	**0.5**	**1.04**	**0.4**	**0.30**
CV (%)	**0.0%**	**1.4%**	**1.9%**	**1.5%**	**2.3%**	**1.3%**	**0.7%**
Both Dummies							
Mean	**6.03**	**48.1**	**46.06**	**32.5**	**46.17**	**29.7**	**45.32**
Standard Deviation	**0.01**	**0.5**	**0.79**	**0.5**	**0.83**	**0.3**	**0.59**
CV (%)	**0.1%**	**1.1%**	**1.7%**	**1.5%**	**1.8%**	**0.9%**	**1.3%**

Table V-43. Pelvis Certification Results

Dummy No./ Test No.	Impactor Velocity (m/s)	Max. Impactor Force (N)	Time of Max. Impactor Force (ms)	Max. Pubic Symphysis Force (N)	Time of Max. Pubic Symphysis Force (ms)
Specification	4.2-4.4	4400-5400	10.30-15.50	1040-1640	9.90-15.90
070/1	4.33	5055	13.52	1387	14.86
070/2	4.44	5317	13.82	1476	15.26
070/3	4.43	5376	13.72	1473	14.38
070/4	4.33	4976	13.88	1348	15.50
070/5	4.32	5039	14.64	1391	15.66
071/1	4.32	5198	13.20	1357	13.66
071/2	4.31	5351	13.96	1380	14.80
071/3	4.29	5337	14.30	1387	15.08
071/4	4.31	5208	13.80	1376	14.22
071/5	4.29	5289	14.86	1398	15.30
Dummy 070					
Mean	**4.37**	**5153**	**13.92**	**1415**	**15.13**
Standard Deviation	**0.06**	**181**	**0.43**	**57**	**0.52**
CV (%)	**1.4%**	**3.5%**	**3.1%**	**4.0%**	**3.4%**
Dummy 071					
Mean	**4.30**	**5277**	**14.02**	**1380**	**14.61**
Standard Deviation	**0.01**	**71**	**0.61**	**15**	**0.67**
CV (%)	**0.3%**	**1.3%**	**4.4%**	**1.1%**	**4.6%**
Both Dummies					
Mean	**4.34**	**5215**	**13.97**	**1397**	**14.87**
Standard Deviation	**0.05**	**145**	**0.50**	**43**	**0.63**
CV (%)	**1.2%**	**2.8%**	**3.6%**	**3.1%**	**4.2%**

Chapter VI. Sled Tests

VI.1 Overview

Data listed in this chapter provide a summary of sled tests performed by NHTSA with ES-2 and ES-2re dummies. Tests described in this report were conducted at the Medical College of Wisconsin (MCW) with ES-2 and ES-2re dummies, and by VRTC with ES-2 re dummies only. Tests at MCW were performed to study the ES-2 and ES-2re dummies' impact response characteristics, biofidelity and injury assessment capabilities, and the equivalence of the responses in several test configurations. Sled tests at VRTC with ES-2 re dummies' were conducted primarily for the purpose of establishing repeatability and reproducibility of the impact response in two test environments and to confirm the dummies' ability to operate without malfunction under overload conditions.

VI. 2. Sled Tests at Medical College of Wisconsin

Sled tests at the MCW were initially conducted with two ES-2 dummies (S/N 9 and S/N 10). They were subsequently modified to the ES-2re versions. The MCW tests were conducted to study how well the ES-2 dummy met the performance, biofidelity and injury assessment goals established by the EEVC, and how well it would meet the needs of the agency for occupant protection assessment in side impact crashes. Upon conversion of the dummy to ES-2re, some of the tests were repeated to verify the equivalence of the two versions of the same dummy. The ES-2 re is basically the same dummy as the ES-2 except that it contains rib extensions and back plate modifications at the back of the dummy's upper torso to prevent its "grabbing" of the vehicle's seat back in side impact tests.

Table VI-1 lists 27 impact exposures that the dummies were subjected to in tests at MCW. They included ten tests of the ES-2 and seventeen of the ES-2re dummies.

Table VI-1. Test Frequency

tstcfn	Dummy	S/N	# of tests
PHF	ES2	9	2
PHF	ES2re	9	1
PHF	ES2	10	2
PHF	ES2re	10	2
PLF	ES2re	10	1
PLOP	ES2re	10	2
RHF	ES2re	10	2
RHOP	ES2re	10	1
RLF	ES2	9	2
RLF	ES2re	10	2
RLOA	ES2	10	2
RLOA	ES2re	10	2
RLOP	ES2re	10	2
RLOT	ES2	10	2
RLOT	ES2re	10	2

Nomenclature for Table VI-1
PHF: Padded high speed flat wall
PLF: Padded low speed flat wall
PLOP: Padded low speed pelvic offset
RHF: Rigid high speed flat wall
RHOP: Rigid high speed pelvic offset
RLF: Rigid low speed flat wall
RLOA: Rigid low speed abdominal offset
RLOP: Rigid low speed pelvic offset
RLOT: Rigid low speed thorax offset

VI.2.1 Sled Apparatus

The MCW deceleration sled and the load impact wall used in these tests are of the Heidelberg design [19]. The ES-2 dummies were seated on the bench of the side impact sled approximately one meter from the load wall. Change in the impact velocity to the dummy was achieved by deceleration and rebound of the sled.

The impact load wall was divided into four sections, one each to contact the thorax, abdomen, pelvis and legs (Figure VI-1). Force transducers between the sled and load plates measured occupant loads from each body region. The change in sled velocity was either 6.7 or 8.9 (± 0.3) m/s. The load wall was either rigid or padded with 10 cm thick LC200 cushion (compressive stiffness = 103 kPa). The geometry of the load wall was also a variable. Load plates were either fixed in the same plane (flat wall) or with thoracic, abdominal or pelvic plates offsets (leads), one at a time per test. They were moved toward the occupant by 11 cm. In flat wall and pelvic offset tests, the dummy was seated with arms down, such that the arm was interposed between the thorax and the load wall. In thoracic and abdominal offset tests, the arms were raised to expose the thorax and abdomen directly to impact by designated protrusions in the load wall.

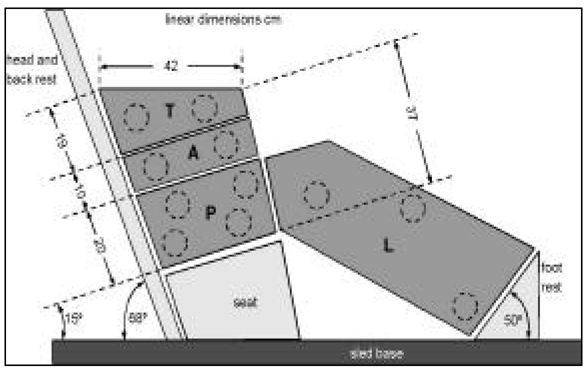

Figure VI-1 MCW/VRTC side impact buck showing load plates for thorax (T), abdomen (A), pelvis (P) and leg (L).

VI.2.2 Summary of MCW sled test results

Table VI-2 lists the configurations for the test matrix. Table VI-3 shows the dummies' peak response values of nine instrumented measurements for of all of the 27 dummy test exposures. While the amount of data in the MCW tests is insufficient to evaluate the dummy responses on a sound statistical basis for the effects of variations of the impact exposures, the test results indicate that measured values are directionally correct. The measurements show, for example, the effects of changes on the impact responses due to variations in impact speed, padded vs. rigid impact walls, abdomen vs. thorax impact offsets, etc.

Table VI-2. Sled Test Configurations

tstno	dum1	Serial No.	rest	clsspd	tstcfn
6697	ES2	9	RIG	24.08	RLF
6698	ES2	9	RIG	23.76	RLF
6699	ES2	9	PAD	32.02	PHF
6700	ES2	9	PAD	32.70	PHF
6701	ES2	10	PAD	32.70	PHF
6702	ES2	10	PAD	33.00	PHF
6703	ES2	10	RIG	25.00	RLOA
6704	ES2	10	RIG	24.00	RLOA
6705	ES2re	9	PAD	32.00	PHF
6706	ES2	10	RIG	24.00	RLOT
6707	ES2	10	RIG	24.00	RLOT
6708	ES2re	10	RIG	25.00	RLOT
6709	ES2re	10	RIG	26.00	RLOT
6710	ES2re	10	RIG	24.00	RLOA
6711	ES2re	10	RIG	24.00	RLOA
6712	ES2re	10	RIG	25.00	RLF
6713	ES2re	10	RIG	24.00	RLF
6714	ES2re	10	PAD	33.00	PHF
SD255	ES2re	10	PAD	24.48	PLOP
SD256	ES2re	10	PAD	24.48	PLOP
SD257	ES2re	10	RIG	24.12	RLOP
SD258	ES2re	10	RIG	23.76	RLOP
SD259	ES2re	10	RIG	31.68	RHOP
SD260	ES2re	10	PAD	23.76	PLF
SD261	ES2re	10	PAD	31.68	PHF
SD262	ES2re	10	RIG	31.32	RHF
SD263	ES2re	10	RIG	31.32	RHF

Nomenclature for tables VI-2 through-4:
tstno: NHTSA test number,
tstprf: Test performer
MCW: Medical College of Wisconsin
dum1: ES2 or ES2re (with rib extension)
Serial No.: Serial Number of dummy
clsspd: closing speed in km/h
Tstcfn: test configuration **--** P = padded, R = rigid, H = 32 km/h impact, L = 24 km/h impact, OA = abdominal offset, OP = pelvic offset, OT = thoracic offset;
rest: Restraint
RIG: Rigid; **PAD:** Padded
tstcfn: Test Configuration
spu & spl: lateral upper and lower spine acceleration (g's)
rspu & rspl: resultant upper and lower spine acceleration (g's)
pel & rpel: pelvic and resultant pelvic acceleration (g's)
rlu & rll: left upper and left lower rib acceleration (g's).
thx_f: max. thoracic plate force
abd_f: max. abdominal plate force
pel_f: max. pelvic plate force in Newtons
Dmax: peak ES2 rib deflections in mm

Table VI-3. Peak Measured Values in Sled Tests

tstno	dum1	tstcfn	spu	spl	pel	thx_f	abd_f	pel_f	Upper rib dmax (mm)	Middle Rib dmax (mm)	Lower rib dmax (mm)
6697	ES2	RLF	36	63	69	10177	2561	11258	32.35	44.43	36.97
6698	ES2	RLF	37	63	65	9815	2569	11990	36.11	45.28	36.78
6699	ES2	PHF	37	51	61	8522	3751	12025	39.91	48.78	40.75
6700	ES2	PHF	39	56	66	9419	3926	12558	40.44	48.89	42.36
6701	ES2	PHF	43	56	67	9992	3819	11679	39.48	50.69	45.88
6702	ES2	PHF	45	53	65	9541	3930	12204	40.88	51.23	46.92
6703	ES2	RLOA	37	86	61	576	16234	4622	11.01	5.40	6.00
6704	ES2	RLOA	42	87	64	846	16831	4198	19.33	5.46	8.42
6705	ES2re	PHF	44	52	61	9379	3711	11180	52.96	54.81	49.66
6706	ES2	RLOT	80	67	54	21122	491	7754	56.61	56.87	55.23
6707	ES2	RLOT	79	72	55	22235	486	7442	56.80	56.82	54.69
6708	ES2re	RLOT	91	99	65	24323	490	6962	56.89	57.73	54.79
6709	ES2re	RLOT	93	103	58	25349	493	7586	56.60	58.37	55.16
6710	ES2re	RLOA	46	96	67	969	16952	6756	14.56	4.90	12.31
6711	ES2re	RLOA	43	93	75	1196	16783	6472	15.84	4.56	9.47
6712	ES2re	RLF	30	61	78	9090	2638	13583	41.11	47.16	43.84
6713	ES2re	RLF	30	64	84	9076	2615	13688	39.75	45.68	43.77
6714	ES2re	PHF	39	49	59	9107	3458	11915	49.20	53.84	48.87
SD255	ES2re	PLOP	25	28	36	2818	1042	9566	28.72	22.74	15.65
SD256	ES2re	PLOP	24	27	36	2782	1150	9367	26.56	22.02	17.62
SD257	ES2re	RLOP	31	42	76	3896	465	16133	30.16	22.07	12.78
SD258	ES2re	RLOP	32	43	79	4028	462	16355	30.78	22.04	13.25
SD259	ES2re	RHOP	55	100	142	8550	919	28321	46.43	34.36	24.07
SD260	ES2re	PLF	22	31	37	4628	2064	6806	26.86	33.45	33.8
SD261	ES2re	PHF	34	48	60	8197	3542	10900	43.46	49.32	47.77
SD262	ES2re	RHF	57	105	137	13928	5773	17871	56.19	55.39	53.08
SD263	ES2re	RHF	48	106	131	13084	6176	18396	55.87	55.92	54.29

These tests indicate that ES-2 and ES-2re dummies' responses are reasonably comparable. While the dummy's exposure in a single test for one particular impact condition are not reliable indicators of the overall dummy response, large differences in the impact environment such as padded vs. rigid or high speed vs. low speed impacts provide a somewhat better opportunity to perform such a comparison.

As shown in Table VI-2, there were four tests of ES-2 and three tests of ES-2re dummies in the PHF test condition at similar impact speeds. The subject tests are #6699, 6700, 6701and 6702 for ES-2 and #6705, 6714 and SD261 for the ES-2re dummies, respectively. Averages of the maximum dummy responses in these tests are presented in Table VI-4. These data provide a cursory look at how ES-2 and ES2-2re dummies' respond in similar crash environments.

Table VI-4 ES-2 and ES-2re Average of Peak Impact Responses in Padded Wall Impact Tests

Average of Peak Responses and units	ES-2 Dummies test #6699, 6700, 6701,6702	ES-2re Dummies test # 6705, 6714, SD261
Impact speed range – (km/h)	32.02-33.00	31.68-33.00
Spine upper acceleration (g)	41.0	38.8
Spine lower acceleration (g)	53.9	49.9
Pelvis acceleration (g)	64.8	59.9
Thorax force* - (N)	9368.8	8894.2
Abdomen force* - (N)	3856.4	3570.3
Pelvis force* – (N)	12116.3	11331.4
Upper rib max defl. (mm)	40.2	48.5
Middle rib max defl. (mm)	49.9	52.8
Lower rib max. defl. (mm)	44.0	48.8

*Wall plate load

VI. 3. Sled Tests at VRTC

VRTC subjected the two newly acquired ES-2re dummies (S/N 70 and -71) to a series of sled tests to determine their general response levels and their repeatability and reproducibility (R&R) under highly controlled impact conditions. Each dummy was exposed to five repeats in two types of sled test conditions:

1) Flat rigid wall impact at 6.7 m/s (12.7 g peak, 80 ms duration)
2) Rigid wall with an abdomen offset block impact at 6.7 m/s (12.7 g peak, 80 ms duration)

VI.3.1. Sled Buck Description

To minimize test-to-test variation of sled pulse parameters, VRTC utilized a recently developed Dual Occupant Side Impact Sled Buck (Figure VI-2). This allowed both dummies to be tested simultaneously, insuring their exposure to the same sled pulse for any given test.

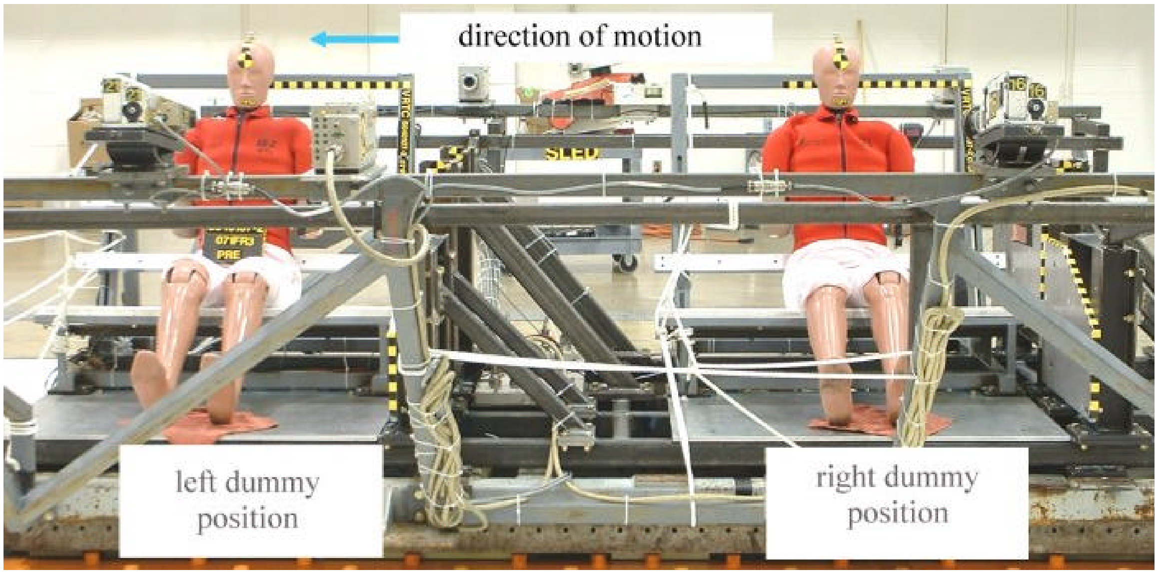

Figure VI-2. Dual Occupant Side Impact Sled Buck

The sled buck incorporated two flat, rigid impact walls (one for each dummy) and Teflon-covered bench seats and seat back simulating two rails to support the reclined dummy's torso. As the sled buck was accelerated, the buck slid beneath the seated dummies, until they impacted the rigid walls with their left side. In order to obtain the desired wall impact speed and to insure that the buck had achieved a constant velocity prior to dummy-to-wall impact, each dummy was pre-positioned on the bench at the same distance from the wall. For the flat wall tests, the dummies were positioned with the struck-side arm down, initially 13 inches away from the wall. The arm was oriented to insure that that it would make first contact with the wall. For the abdomen offset tests, the dummies were positioned with their arms up so that the abdomen would make first contact with the protruding offset block. In this configuration, the dummy's abdomen at set-up was 13 inches away from the offset block. For the flat wall and the abdomen offset test conditions, the load wall was 374 mm high from the front edge of the seat, and 368 mm long from the back of the seat as shown in Figures VI-3.

The abdomen-offset block was designed to provide a test environment with severe loading of the abdominal region. The block was located at the height and orientation to impact the abdomen only, above the pelvis and below the lower rib as shown in Figure VI-4.

VI.3.2. Sled Pulse

The sled pulse, applied for each of the tests, was an approximate half-sine wave, with the peak acceleration of 12.7 g's and duration of 80 ms.

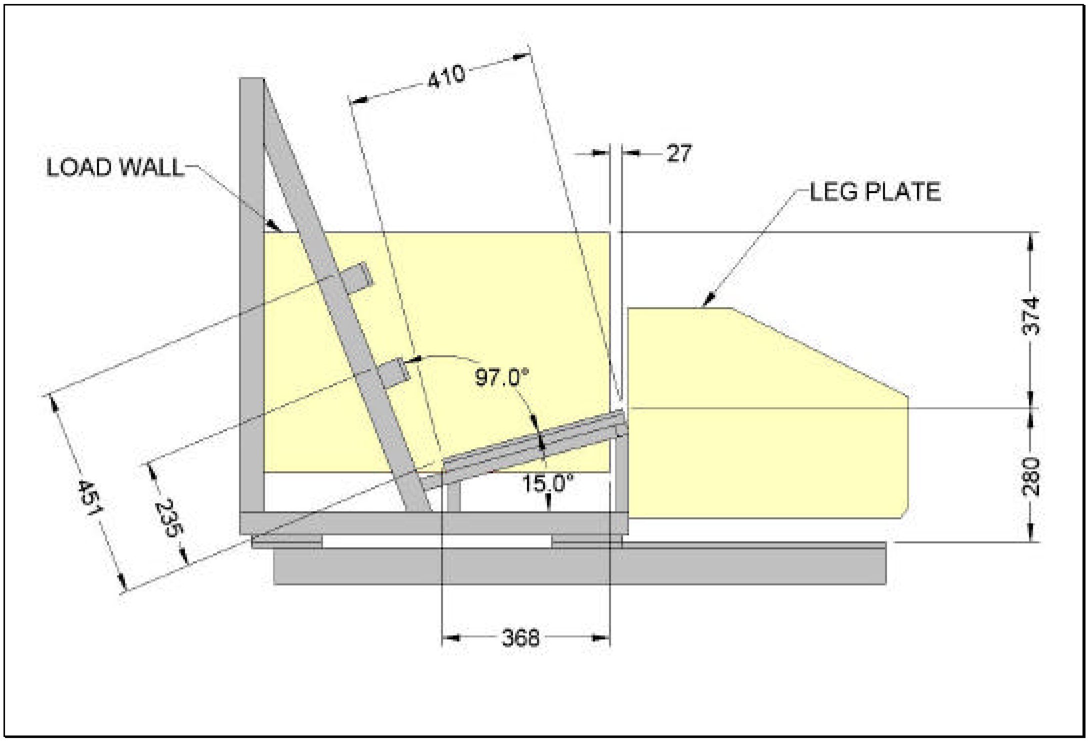

Figure VI-3. Seat Set-up and Impact Wall Dimensions for Flat Wall Sled Tests

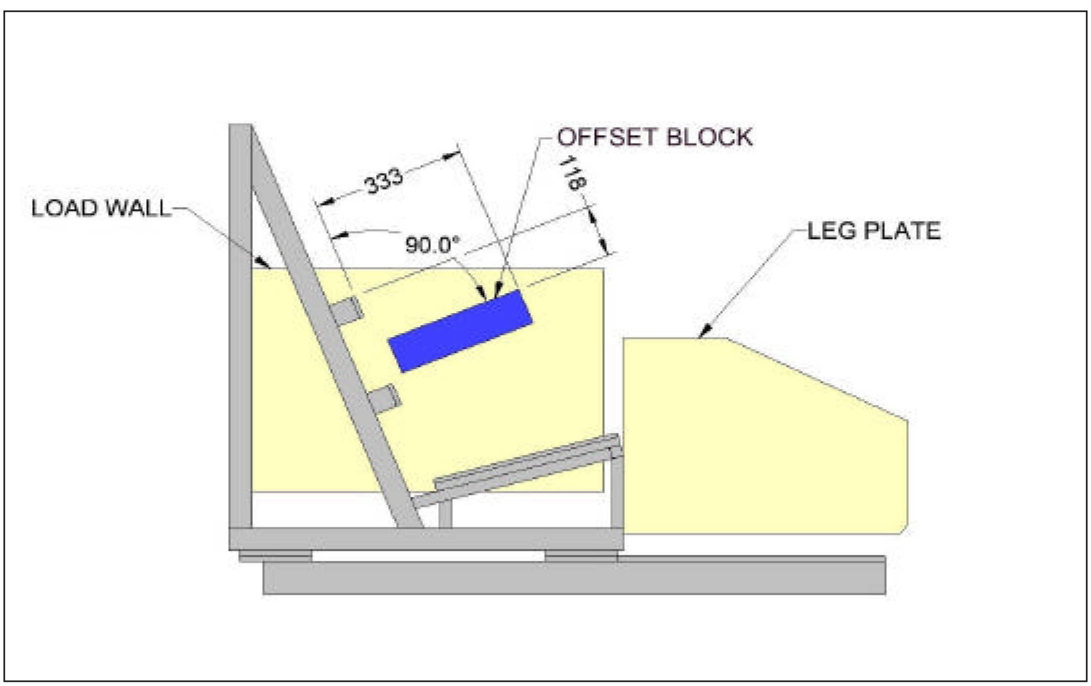

Figure VI-4. Seat Set-up for Abdomen Offset Sled Tests

VI.3.3. Instrumentation

The dummies were instrumented with sensors to record the traditional measures for injury criteria, spine (T1 and T12) accelerations, rib deflections, abdominal, and pelvis loads. Additional data were collected on the upper neck, shoulder, lumbar spine and pubic symphysis responses. A contact switch was positioned on the side of each dummy and on the load wall at the location of first contact to indicate the precise instant of dummy contact with the wall. The data were collected and filtered according to SAE J211, except for several measures as summarized in Table VI-5.

Table VI-5. Instrumentation for ES-2re R&R Sled Series

	Location	Measurement	Direction	CFC	channels per dummy	Total # channels per test
Dummy	Head	Acceleration	X, Y, Z	1000	9	74
	Upper Neck	Force	X, Y, Z	1000	3	
		Moment	X, Y, Z	600	3	
	Shoulder	Force	Y	1000	1	
	Upper Spine (T01)	Acceleration	X, Y, Z	180	3	
	Lower Spine (T12)	Acceleration	X, Y, Z	180	3	
	Ribs	Displacement	Y	180	3	
		Acceleration	Y	1000	3	
	Lumbar	Force	Y	1000	1	
		Moment	X	1000	1	
	Abdomen	Force	Y	600	3	
	Pubic Symphysis	Force	Y	600	1	
	Pelvis	Acceleration	X, Y, Z	1000	3	
Sled	Sled	Acceleration	X	60	1	4
	Sled	Velocity	X	180[1]	1	
	Load Wall	Event	N/A	N/A	2	
TOTAL						**78**

[1] Sled acceleration is filtered at CFC 180 before integration for sled velocity.

VI.3.4 VRTC Sled Tests Results

VI.3.4.1 Flat wall sled test series

Results from ES-2re S/N 70 and 71 dummies' tests in terms of individual peak measured responses of the various body segments in the flat wall impact environment are provided in Table VI-6. In these tests, the unrestrained dummies were positioned in the upright posture with the struck-side arm down, such that the arm was 13 inches away from the wall. The measurements were performed in consecutive tests with no intermittent use of the dummy in crash tests.

The data in the five consecutive tests appear to be consistent, within the bounds of the instrumentation capacity, and within the maximum calibration ranges of applicable components as shown in Chapter V. The dummies did not experience any noticeable structural deficiencies in any of these tests. Further details about the test conditions and data may be found tin the VRTC Technical Report and its Appendix B [20].

VI.3.4.2 Abdominal offset sled test series

Table VI-7 displays test results of the same two dummies in impacts of a rigid wall with the abdominal offset as shown in Figure VI-4. For these tests, the unrestrained dummies were positioned with their arms up so that the abdomen would make first contact with the protruding offset block (Figure VI-5). In this configuration, the dummy's abdomen at set-up was 13 inches away from the offset block.

The data in five consecutive tests appear to be consistent and are within the bounds of the instrumentation capacity. Directionally, the data is reflecting the first abdominal impact that results in higher loads occurring at the lower torso level than those recorded in flat wall impacts. In spite of concentrated penetration of the abdomen and the resulting high forces, the dummies did not experience any noticeable structural deficiencies or discontinuities in any of the data channels during this set of tests. Additional details about the test conditions and data may be found tin the VRTC Technical Report and its Appendix C [20].

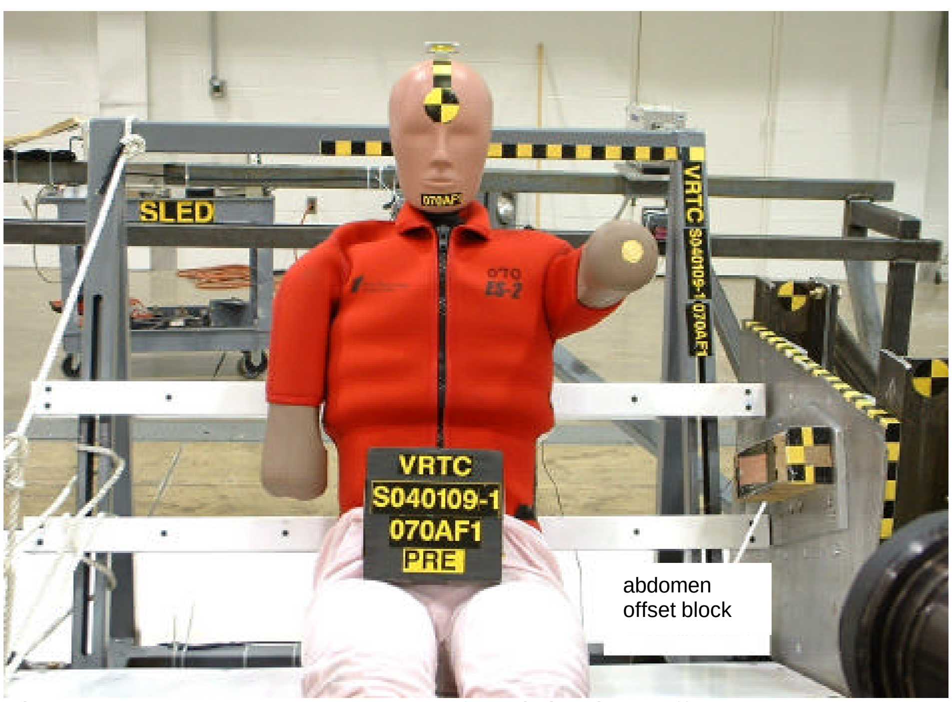

Figure VI-5 ES-2re Dummy Set-up for Abdominal Offset Test

Table VI-6. Summary of Peak Responses in 6.7 m/s Flat Wall Sled Tests

		Dummy S/N		070					071				
		Dummy Locat.		Front	Front	Front	Front	Front	Rear	Rear	Rear	Rear	Rear
Location	**Measurement**	**Direction**	**Units**	S040107-1	S040107-2	S040108-1	S040108-2	S040108-3	S040107-1	S040107-2	S040108-1	S040108-2	S040108-3
Head CG	Acceleration	Y	g	15.3	15.7	14.9	15.1	16.5	12.9	13.9	13.6	13.2	13.4
		Z	g	21.9	21.7	22.1	21.6	21.6	22.9	22.6	23.4	23.7	23.5
		Resultant	g	22.8	22.4	22.8	22.6	23.0	25.2	25.2	26.0	26.2	25.9
Head	Displacement (Front Camera)	Lateral	mm	297.0	289.3	272.0	277.6	280.3	305.6	302.1	291.7	290.9	292.9
		Vertical	mm	-57.1	-54.7	-52.7	-56.3	-57.0	-61.6	-66.1	-58.4	-62.0	-60.8
Upper Neck	Force	Y	N	578.4	573.2	564.0	578.3	597.1	553.9	563.6	554.2	560.1	579.9
		Z	N	908.6	908.6	892.7	908.5	941.0	828.1	855.3	822.0	857.1	847.4
	Moment	+X	N-m	34.8	34.7	34.5	34.2	41.1	34.3	33.2	34.8	33.9	36.0
		-X	N-m	-37.6	-37.3	-34.0	-38.5	-42.4	-33.1	-34.2	-33.6	-33.8	-34.4
Shoulder	Force	Y	N	817.4	887.8	817.5	825.2	927.9	682.1	739.3	727.6	740.0	739.7
T1	Acceleration	Y	g	26.0	25.9	26.5	26.9	26.5	29.4	28.5	28.9	30.3	28.9
		Resultant	g	26.2	28.5	26.6	29.0	28.8	29.9	29.2	29.5	30.9	29.5
T12	Acceleration	Y	g	54.7	53.7	57.2	55.5	51.4	59.7	57.4	59.9	62.0	59.2
		Resultant	g	55.4	54.5	57.7	56.1	52.1	60.1	57.6	60.2	62.2	59.4
Upper Rib	Displacement	Y	mm	37.0	37.7	37.4	37.3	38.8	43.9	43.2	45.4	44.4	45.5
Middle Rib	Displacement	Y	mm	42.0	42.6	42.3	41.9	42.0	45.5	45.7	46.7	46.5	46.8
Lower Rib	Displacement	Y	mm	39.4	39.9	39.8	39.4	39.1	41.4	40.8	41.5	41.3	41.9
Abdomen-Front	Force	Y	N	341.7	341.0	377.8	406.0	348.0	337.7	317.4	342.1	361.4	345.1
Abdomen-Center	Force	Y	N	595.0	607.9	666.5	618.9	542.0	628.5	596.2	638.4	681.2	647.9
Abdomen-Rear	Force	Y	N	451.4	473.7	506.7	446.1	423.4	546.4	496.5	537.7	561.1	521.7
Abdomen-Sum *	Force	Y	N	1375.0	1404.3	1528.9	1450.2	1302.9	1504.8	1402.3	1506.2	1592.1	1510.1
Lumbar	Force	Y	N	541.3	582.0	721.1	621.8	490.6	817.6	670.0	826.2	808.0	687.5
	Moment	+X	N-m	61.7	62.0	65.1	59.7	60.9	64.8	67.8	66.4	65.3	65.5
Pubic Symphysis	Force	Y	N	-3288.2	-3552.3	-3634.8	-3390.4	-3361.7	-3264.5	-3060.9	-3335.3	-3293.5	-3285.5
Pelvis	Acceleration	Y	g	74.2	85.2	87.9	90.2	82.8	79.6	80.3	88.3	86.1	86.9
		Resultant	g	83.2	85.3	87.9	90.7	83.2	79.8	80.7	88.4	86.4	87.4

Table VI-7. Summary of Peak Responses in 6.7 m/s Abdomen Offset Sled Tests

	Dummy SN		070					071				
	Dummy Location		Front	Front	Front	Front	Front	Rear	Rear	Rear	Rear	Rear
Measurement	**Direction**	**Units**	S040109-1	S040112-1	S040112-2	S040113-1	S040113-2	S040109-1	S040112-1	S040112-2	S040113-1	S040113-2
Acceleration	Y	g	21.6	20.9	21.6	21.0	20.9	21.2	20.9	19.5	20.7	19.0
	Z	g	31.1	28.9	29.6	31.6	28.9	31.2	30.9	28.0	29.5	26.3
	Resultant	g	36.0	34.6	35.7	36.7	34.8	36.9	36.4	32.9	35.1	30.7
Displacement (Front Camera)	Lateral	mm	346.5	350.7	352.3	347.2	356.6	340.8	344.6	361.9	356.6	360.1
	Vertical	mm	-150.3	-142.4	-147.4	-154.4	-145.6	-155.9	-162.6	-159.8	-155.9	-149.5
Force	Y	N	589.5	578.4	573.3	579.4	564.8	600.1	577.8	534.6	562.9	525.3
	Z	N	1056.5	937.1	938.2	986.4	901.5	1092.3	1041.7	944.5	982.9	866.7
Moment	+X	N-m	64.9	63.6	61.9	62.5	62.8	60.9	60.8	59.8	58.7	56.6
	-X	N-m	-80.9	-84.4	-83.3	-82.0	-83.2	-80.0	-81.2	-80.6	-81.4	-82.0
Force	Y	N	-883.7	-887.9	-864.5	-876.1	-863.6	-838.0	-857.1	-879.2	-843.0	-813.5
Acceleration	Y	g	70.1	69.1	67.6	66.8	67.8	73.0	74.1	68.7	69.5	65.9
	Resultant	g	70.3	69.2	67.7	67.2	68.0	73.0	74.1	68.7	69.5	66.0
Acceleration	Y	g	85.2	90.1	90.6	90.6	90.0	92.9	93.1	93.8	95.4	95.5
	Resultant	g	85.5	90.3	90.8	90.8	90.1	93.4	93.9	94.4	96.0	96.0
Displacement	Y	mm	24.0	20.8	20.6	21.9	21.1	26.5	26.4	24.6	24.8	23.7
Displacement	Y	mm	14.7	13.3	13.5	14.3	13.9	14.7	14.9	13.7	14.1	12.9
Displacement	Y	mm	14.2	12.1	12.0	12.7	12.4	11.0	10.8	9.7	10.4	9.5
Force	Y	N	842.2	1140.9	1162.1	1164.1	1187.4	943.7	1293.5	1409.5	1339.1	1443.1
Force	Y	N	3004.1	3803.1	3824.1	3707.7	3902.8	3436.8	3975.5	4264.1	4277.4	4606.0
Force	Y	N	1615.5	1765.7	1715.4	1641.2	1734.6	1800.0	1736.4	1784.2	1887.6	1969.0
Force	Y	N	5422.8	6685.0	6681.6	6496.6	6804.6	6142.4	6993.0	7432.6	7475.6	7993.5
Force	Y	N	-2337.9	-2759.0	-2909.2	-2856.0	-2921.4	-2275.7	-2569.2	-2582.6	-2574.9	-2628.3
Moment	+X	N-m	54.6	63.6	65.9	67.3	67.3	41.7	45.8	51.3	51.8	46.0
Moment	-X	N-m	-125.7	-150.3	-154.0	-148.0	-153.5	-120.4	-128.7	-132.3	-135.3	-136.7
Force	Y	N	-2448.4	-2611.3	-2411.4	-2584.9	-2502.8	-2275.7	-2357.6	-2650.5	-2516.6	-2598.9
Acceleration	Y	g	98.0	102.8	99.8	97.6	99.6	98.0	102.7	106.8	108.8	109.0
	Resultant	g	98.7	102.8	102.3	102.0	101.4	98.9	103.8	107.7	109.2	109.1

VI.3.4.4 Comparison of flat wall to abdominal offset sled test series

The flat wall to abdominal offset sled test series subjected the dummies to severe loading conditions. The averages of peak responses of the two dummies provide a glimpse of how the dummies respond to the two different impact environments. The results are displayed in Table VI-8. In the flat wall test condition, the dummies' chest deflections are significantly higher than those receiving an abdominal offset impact. In contrast, impacts with abdominal offset resulted in considerably elevated abdominal and lumbar loads and pelvis accelerations.

Table VI-8. Comparison of Impact Response Averages in Flat Wall and Flat Wall Offset Impacts

			Impact Environment	Flat Wall	Flat Wall with Abdomen Offset
			Dummies	070&071	070&071
Location	Measurement	Direction	Units	AVG	AVG
Head CG	Acceleration	Y	g	14.5	20.6
		Z	g	22.5	29.2
		Resultant	g	24.2	34.6
	HIC-36	Resultant		51.9	53.3
Head	Displacement (Front Camera)	Lateral	mm	289.9	353.8
		Vertical	mm	-58.7	-152.2
Upper Neck	Force	Y	N	570.3	562.1
		Z	N	876.9	949.9
	Moment	+X	N-m	35.1	60.8
		-X	N-m	-35.9	-82.3
Shoulder	Force	Y	N	790.4	-860.6
T1	Acceleration	Y	g	27.8	68.7
		Resultant	g	28.8	68.8
T12	Acceleration	Y	g	57.1	92.4
		Resultant	g	57.5	92.8
Upper Rib	Displacement	Y	mm	41.1	23.0
Middle Rib	Displacement	Y	mm	44.2	13.8
Lower Rib	Displacement	Y	mm	40.5	11.2
Abdomen-Front	Force	Y	N	351.8	1267.5
Abdomen-Center	Force	Y	N	622.2	4045.1
Abdomen-Rear	Force	Y	N	496.5	1779.3
Abdomen-Sum	Force	Y	N	1457.7	7070.3
Lumbar	Force	Y	N	676.6	-2725.1
	Moment	+X	N-m	63.9	57.4
	Moment	-X	N-m	not reported	-142.4
Pubic Symphysis	Force	Y	N	-3346.7	-2529.3
Pelvis	Acceleration	Y	g	84.2	103.4
		Resultant	g	85.3	104.8

Chapter VII Biofidelity

Two methods are currently available for assessing the biofidelity of a dummy in side impact testing: 1) the ISO procedure defined as ISO 9790 methodology [21] and 2) the newly developed NHTSA Bo fidelity Ranking system [16]. The biofidelity of a dummy by the ISO methodology is determined by how well does the dummy's body segment and/or subsystem impact responses replicate cadaver responses in a series of defined impact environments. The NHTSA Biofidelity Ranking System is based on two biofidelity assessment measures: (1) the ability of a dummy to load a vehicle as a cadaver does, termed "External Biofidelity" and (2) the ability of a dummy to replicate those cadaver responses that best predict injury potential, termed "Internal Biofidelity". The NHTSA biofidelity ranking system evaluates the dummy's ability to replicate the cadaver loading responses more at the whole body level and how that body replicates the loading of interfacing external structures. The following discussion provides an assessment of the biofidelity levels of the ES-2re dummy by these two distinctly different evaluation procedures.

VII.1 Biofidelity Assessment per ISO 9790 Methodology

The International Standards Organization in a 1988 Technical Report ISO TR 9790-1 through -6 [21] describes test procedures and impact response requirements for assessing the biofidelity of a dummy in side impact testing. The evaluation consists of drop tests, impactor tests and sled tests of the head, neck, shoulder, thorax, abdomen, and pelvis. The dummy responses in these tests are compared to impact responses of human cadavers under identical impact conditions. The ISO document N455, updated by ISO/TC22/SC12/WG5 in 1997 and published in 1999 [22], includes the determination of an overall biofidelity rating of the dummy. Further guidelines for assessing the biofidelity of side impact dummies may be found in reference [15, 23].

The ISO biofidelity tests are defined in ISO TR 9790. It consist of two types of head drop tests, three types of lateral neck bending tests, four types of shoulder impact tests, six types of lateral thoracic tests, five abdominal test conditions and thirteen lateral pelvis impact tests. The dummy's responses are evaluated by ISO developed weighting for various test conditions and the criticality of the responses for a given body region. The measured value is assessed by how well the dummy responds relative to the established cadaver response corridors. A value of 10 is given if the dummy's segment response is completely within the boundaries of cadaver response. A value of 5 is given if the dummy's segment response is outside of the boundaries of cadaver response but lies within one corridor width (defined in most instances as one standard deviation and in others by subjective group judgment to encompass the data). It is rated zero if neither of the above set is met.

The overall dummy biofidelity is found by weighted average of the scores of different body regions. The weights used in the averaging process were established by consensus of an expert panel. Five classifications indicate the degree of biofidelity of the overall dummy rating. They are provided in Table VII-1.

Table VII-1 ISO Biofidelity Classification

Excellent	**> 8.6 to 10**
Good	**> 6.5 to 8.6**
Fair	**> 4.4 to 6.5**
Marginal	**> 2.6 to 4.4**
Unacceptable	**0 to 2.6**

Using the ISO 9790 methodology, the ES-2re and the SID/HIII dummies were found to have component and overall biofidelity ratings as shown in Table VII-2. The ES-2 rating is based on Byrnes et al. [15]. In as much as the ES-2 and ES-2re dummy conform to the same calibration levels, it is assumed that the ES-2 conversion to ES-2re had no effect on its ISO based biofidelity assessment. This assumption has been confirmed by the evaluation of the two dummies using the NHTSA Biofidelity Ranking System (Tables VII-3 and –4. show essentially the same ranking for the ES-2 and ES-2re dummies). The SID/HIII includes a Hybrid III type head and neck specially designed for side impact, and its rating was published in the Final Rule on Side Impact Anthropomorphic Test Dummies, August 4, 1998 [23].

Table VII-2 ISO Biofidelity Comparison

	ES-2re	**SID/HIII**
Head	5	6.7
Neck	4.4	6.1
Shoulder	5.3	0.0
Thorax	5.2	3.2
Abdomen	2.6	4.4
Pelvis	5.3	2.7
Overall	4.6	3.9

VII. 2 ES-2re Biofidelity Ranking per NHTSA Assessment Procedure

As part of research program to upgrade the evaluation and quality of dummies, the National Highway Traffic Safety Administration's has developed a quantitative and objective biofidelity ranking system based upon new test data. The NHTSA ranking system was developed by Rhule et al. and presented at the 46th Stapp Car Crash conference (#2002-22-0024) [16]. The system quantifies (1) the ability of a dummy to load a vehicle as a cadaver does, termed "External Biofidelity" and (2) the ability of a dummy to replicate those cadaver responses that best predict injury potential, termed "Internal Biofidelity." External Biofidelity is calculated using measures external to the test dummy and Internal Biofidelity is calculated using dummy based instrumentation. Like the ISO TR 9790 biofidelity rating system, the NHTSA ranking system is based on cadaver and dummy responses, i.e. for side impact on head drop tests, thorax and shoulder pendulum tests, and whole body sled tests. The NHTSA ranking system also introduced the abdominal and pelvic offset sled test conditions, which exercises the lumbar and thoracic spine of the dummy and helps insure biofidelic transfer of load between the torso and pelvis. Each test condition is assigned a weight factor based on the number of human subjects tested to form the biomechanical response corridor and how well the biofidelity tests represent the particular crash environments. For each response requirement, the cumulative variance of the dummy response relative to the mean cadaver response (DCV) and the cumulative variance of the mean cadaver response relative to the mean plus one standard deviation (CCV) are calculated. The ratio of DCV/CCV expresses how well the dummy response duplicates the mean cadaver response: a smaller ratio indicating better biofidelity. For each test condition, the square root is taken of each response comparison value, and then these values are averaged and multiplied by the appropriate test condition weight. The weighted and averaged comparison values are then summed and divided by the sum of the test condition weights. Each dummy obtains an overall rank for External Biofidelity and an overall rank for Internal Biofidelity, each comprised of an average of the ranks from each body region. Opposite from the ISO biofidelity ranking, the new biofidelity lower ranking number indicates a higher level biofidelity, i.e. biofidelity of two indicates that the dummy responds with the same impact response dispersion range as cadavers.

Although this method does not establish an "absolute" ranking scale, the ranks provide a relative sense of the "number of standard deviations away" are from the mean human response. Rhule conducted an analysis and found that if the dummy biofidelity ranking is below two, then the dummy is behaving similar to the human cadaver. The evaluation methodology is intended to be as objective as possible to allow both a comparison of dummy response to cadaver response as well as to compare two or more dummies

The Rhule 46th Stapp Car Crash conference paper [16] contains external and internal biofidelity rankings for the ES-2 dummy with back plate changes. The ES-2re dummy with rib extension changes was retested using the same techniques as used by Rhule et al. for the ES-2 dummy. Table VII-3 provides a summary of external biofidelity rankings and Table VII-4 internal biofidelity rankings for the ES-2re, ES-2, and the SID/HIII crash test dummies.

Table VII-3 External Biofidelity Ranking of the ES-2re, ES-2 and SID/HIII

External Biofidelity	ES-2 (re)	ES-2	SID/HIII
Overall Rank	2.6	2.7	3.8
Head/Neck Rank	3.7	3.7	1.0
Shoulder Rank	1.4	1.4	5.1
Thorax Rank	2.9	3.2	6.1
Abdomen Rank	2.6	2.5	3.0
Pelvis Rank	2.7	2.7	3.8

Table VII-4 Internal Biofidelity Ranking of the ES-2re, ES-2 and SID/HIII

Internal Biofidelity	ES-2 (re)	ES-2	SID/HIII
Overall Rank with T1 (w/o abdomen)	1.5		n/a
Overall Rank with Defl. (w/o abdomen)	1.6	1.6	n/a
Overall Rank with TTI (w/o abdomen)	1.6	n/a	1.9
Head Rank	1.0	1.6	1.1
Thorax Rank – T1	1.5	n/a	n/a
Thorax Rank - Delft	1.8	1.7	n/a
Thorax Rank - TTI	1.8		2.2
Abdomen Rank	n/a	n/a	n/a
Pelvis Rank	2.0	2.1	2.5

VII-3 Conclusion

The results of NHTSA Biofidelity Ranking System tests, shown in Tables VII-3 and -4, indicate that the ES-2 and ES-2re dummies have essentially the same internal and external biofidelity assessment values. Accordingly, it is concluded that the rib extension revision has had no effect on the biofidelity of ES-2 dummy. The tables also indicate that the ES-2 and the ES-2re dummies have higher levels of biofidelity than the SID/HIII dummy by both the ISO and the Biofidelity Ranking System ratings.

Chapter VIII Directional Impact Sensitivity

VIII.1 Introduction

This chapter addresses the sensitivity of the ES-2re dummy responses to directional impact. The agency conducted repeat pendulum impacts to determine the effects of impact angle changes on the responses of the shoulder and thorax. This chapter provides data from these tests and an assessment of the dummy's sensitivity.

Directional sensitivity assessment of the ES-2 dummy was reported by EEVC in its document of August 2001 [2]. The EEVC performed 72 full body pendulum tests on the shoulder, thorax, abdomen, and pelvis. The report notes that " The ES-2 rib deflection gave results below those for pure lateral impacts for the forward oblique condition, whilst rearward oblique tests gave slightly higher results… The ES-2 abdomen was less responsive to changes in impact angle than the thorax...The pelvis had a low sensitivity to changes in impact angle for the forward oblique and pure lateral tests, tests in the frontal oblique condition resulted in higher pubic force."

To assess the directional sensitivity of the ES-2re dummy, NHTSA initially evaluated the response of the ES-2re thorax to pure lateral and +30 degrees oblique anterior to posterior impacts[1] (series 1). Subsequently, the agency performed additional pendulum tests in + 30, + 15, 0 and -15 degrees oblique impacts on newly purchased dummies to determine the effects of smaller increments in the angle of impact on the responses of the shoulder and the thorax (series 2).

VIII.2. Oblique thorax impact tests - series 1

VIII.2.1. Test set-up

A series of twelve pendulum impact tests were conducted on S/N 9 ES-2re dummy. Six tests were conducted at 4.3 m/s, and six at 6.5 m/s. At each impact speed, three tests were made at pure lateral impact angle and three at +30 degrees oblique anterior orientation.

The test set-up used a 152.4 mm diameter pendulum having a mass of 23.4 kg to impact the dummies. The dummy's midsaggital plan was oriented either perpendicular to the trajectory of the impact probe or at an oblique +30 degree angle. The dummy's arm was positioned such that the probe directly impacted only the ribs. The probe was aligned so that its trajectory passed through the c.g. of the thorax. The pendulum alignment through the c.g. was to assure no torso rotation from the impact.

For each test, pendulum acceleration along with dummy T01 X- and -Y-axis accelerations, and upper, lower, and middle rib deflections and accelerations were recorded. The Y-axis deflection, T01 X, -Y, and -Z-axis accelerations and impact force signals were filtered at FIR 100. FIR 100 filtering allows direct comparison with the cadaver data and the ISO data processing corridors. The data also include SAE J211 CFC 180 filtered data to permit a direct comparison with test data performed in series 2.

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[1] Oblique impact – an impact angle orientation relative to the transverse (lateral) plane of the dummy: (+) sign or (anterior) means vector rotation forward of the dummy and (-) sign or (posterior) means vector rotation rearward of the dummy.

VIII.2.2. Test results

VIII.2.2.1 Lateral rib deflections

The average of maximum compression type displacements of the three thoracic ribs was computed. This value was then averaged for the three repeat tests. The ribcage compressions in the +30 deg. oblique tests were about 6 to 10 mm less than in the pure lateral 0 deg. tests. The dummy chest deflections in the oblique impact conditions peaked prior to those in lateral impacts (Figures Al and A2)[]. The average peak rib displacement ratio for oblique to lateral impacts was 0.81 and 0.81 for 4.3 m/s and 6.7 m/s impacts, respectively (Table VIII-I).

Table VIII-1. Average Rib Displacement Comparison

Dummy	Impact Speed (m/s)	Displacement (mm) Impact Angle (deg)		Average Peak Rib Displacement Ratio Oblique/ Lateral
		0	+30	
ES-2 re FIR filter	4.3	32.3	26.0	0.81
	6.7	46.8	37.4	0.80
ES-2 re CFC 180	4.3	32.3	26.0	0.81
	6.7	47.0	37.5	0.80

VIIL2.2.2. T01 spine acceleration

Accelerations from the three repeat tests were averaged. At both low and high- speed impacts the T01 lateral acceleration from +30 degree oblique tests exceeded the ones measured in purely lateral impacts (Figures A3 and A4). At 4.3 m/s impact speed, a change in impact angle from 0 to +30 degrees increased the peak lateral acceleration by 20% (ratio of oblique to lateral T01 accelerations equaled 1.20) (Table VIII-2). At 6.7 m/s impact speed, a change in impact angle from 0 to +30 degrees increased the peak lateral acceleration by approximately 40% (ratio of oblique to lateral T01 accelerations was 1.44) (Table VIII-2).

Table VIII-2. Average T01 Acceleration Comparison

Dummy	Impact Speed (m/s)	T01 Y Axis Acceleration (g) Impact Angle (deg)		Average Peak T01 Y-Axis Acceleration Ratio Oblique/ Lateral	T01 Resultant Acceleration (g)* Impact Angle (deg)		Average Peak T01 Resultant Acceleration Ratio Oblique/ Lateral
		0	+30		0	+30	
ES-2 re FIR filter	4.3	16.7	20.0	1.20	16.8	27.4	1.63
	6.7	25.6	36.9	1.44	25.6	52.9	2.07
ES-2 re CFC 180	4.3	18.8	23.9	1.27	18.9	30.9	1.63
	6.7	29.2	40.6	1.39	29.3	52.4	1.79

* ES-2 re also includes a small z component in the resultant.

Although of less significance, the ES -2 re dummy showed, as expected, an increase in the magnitude of the X-axis acceleration in +30 degrees oblique impacts as compared to the one measured in 0 degrees lateral impacts.

VIII.2.2.3. Pendulum force

The maximum pendulum forces from the three repeat thorax tests were averaged. Pendulum force time histories at 4.3 m/s d 6.7 m/ for 0 degrees lateral impacts are bimodal whereas the 30 degrees oblique impact curves approximate a unimodal shape. For impacts at 4.3 m/s and 6.7 m/s, the change in the impact angle from 0 to +30 degrees increased the impact force by 25 and 39 percent, respectively (Table VIII-3).

Table VIII-3. Average Peak Impact Force Comparison

Dummy	Impact Speed(m/s)	Average Peak Impact Force -kN Impact Angle (deg)		Average Peak Impact Force Ratio Oblique/ Lateral
		0	+30	
ES-2 re FIR filter	4.3	4.9	6.2	1.25
	6.7	7.8	10.9	1.39
ES-2 re CFC 180	4.3	6.85	6.24	0.91
	6.7	13.3	11.2	0.84

VIII.3. Shoulder and Thorax Impact Test - Series 2

VIII.3.1. Test set-up

VIII.3.1.1 Oblique shoulder impacts

Lateral and oblique shoulder impact tests were performed to compare the responses of the S/N 71 ES-2re shoulder assembly to post mortem human subject's (PMHS) shoulder impact test results reported by Bolte et al in 2003 [24]. Test procedures and conditions used by Bolte et al. were reproduced as closely as possible so that reasonable comparisons could be made between the PMHS and the ES-2re shoulder responses.

The tests were performed using a P572 subpart E pendulum impactor with a mass of 23.4 +/- 0.02 kg and a diameter of 152.4+/-2.4 mm. The face of the impactor was covered with a 152 mm square, 50 mm thick Arcel 310 padding having a density of 26.4 kg/m^3. The lateral tests were performed with the dummy seated on a Teflon-covered seat with a seat base angle of approximately 15 degrees elevated from horizontal and a seat back angle of approximately 23 degrees back from vertical. The oblique tests were performed with the dummy seated in a 1996 Ford Taurus bucket seat that is the same as used by Bolte et al. in trauma tests. All tests were performed at an impactor speed of 4.4 m/s.

The dummy was instrumented with two tri-axial accelerometers installed at the top on the outer edge of each clavicle to measure shoulder acceleration in the dummy's X, Y and Z vectors. Overhead and frontal video cameras were used for image analysis.

The dummy (without the suit and foam shoulder cap) was positioned squarely in the seat so that the thorax midsagittal plane was vertical and the torso back plate was parallel with the seat back plane and the dummy's torso resting against the seat back. The seat was moved vertically to center the shoulder bolt 50 mm above the bottom edge of the ram face.

The tests were performed with the dummy positioned at three angles relative to the longitudinal centerline of the impactor at 0 degrees (Figure VIII-I), at +15° (Figure VIII-2) and + 30°. The seat was positioned in the fore/aft direction to align the longitudinal centerline of the pendulum with intersect at the center of the outer edge of clavicle. For all tests, the dummy' arms were positioned vertically, pointing downward.

The impactor, and left and right shoulder X-, Y-, and Z-axis accelerations were recorded and the data digitally filtered using SAE J211 CFC 180. Impactor force was calculated by multiplying the impactor acceleration by its mass. The impactor force for the oblique tests was resolved into the Y-axis component based on the dummy's Y-axis coordinate. Shoulder-to-shoulder Y-axis displacement was calculated by double integrating the accelerometer data and verified by motion image analysis. The accelerometer data was used for the force versus displacement data plots.

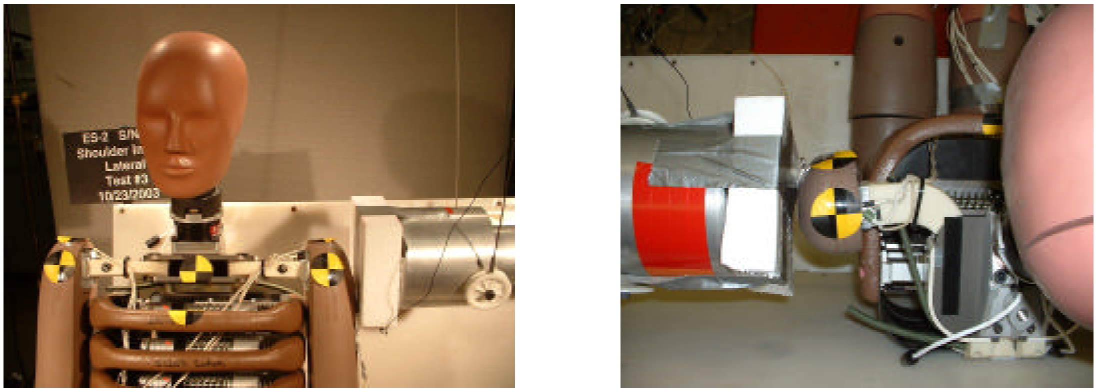


Figure VIII-1. +0° Shoulder Impact Front & Top Views

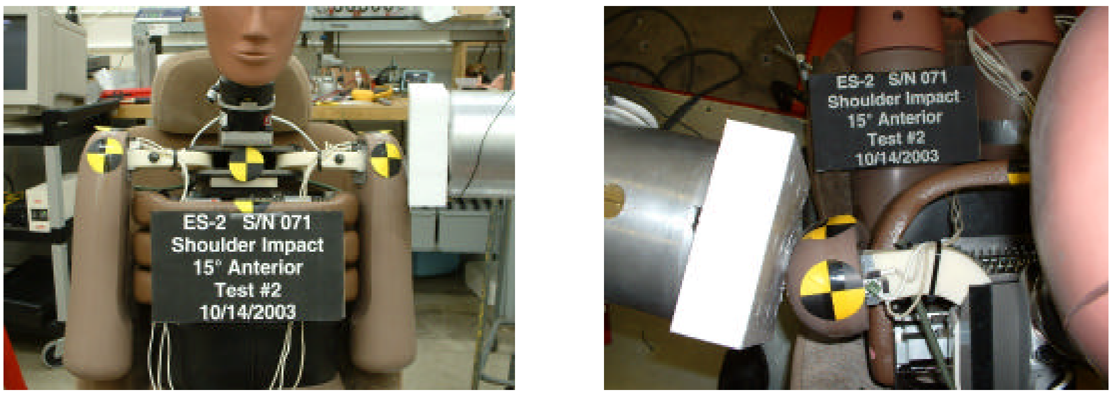


Figure VIII-2. +15° Shoulder Impact Front & Top Views

VIII.3.1.2 Oblique Thorax Impacts

Oblique thoracic pendulum impact tests were conducted to assess the performance of the thorax assembly in angled impacts. The tests were performed using a Part 572 Subpart E pendulum impactor having a mass of 23.4 +/-.02 kg and a diameter of 152.4 +/- .25 mm. The dummy (without suit and foam shoulder cap) was seated on a flat, horizontal, rigid surface without back support. Two sheets of 2 mm-thick Teflon were placed between the dummy and the surface.

The tests were performed with the dummy positioned at four angles relative to the longitudinal centerline of the impactor: at 0° (Figure VIII-3), + 15°, +30° (Figure VIII-4) and at -15°(Figure VII-5). Three tests were performed at each orientation. For the oblique tests, the dummy was positioned in the fore-and-aft direction to allow the extended longitudinal centerline of the pendulum to intersect the spine box at the same location as in lateral tests. This point was on the dummy's midsagittal plane, approximately at the anterior edge of the top of the spine box. For all tests, the center of the impactor face was aligned vertically with the center of the middle rib. The torso back plate was vertica1 and the arms were vertical, pointing upward. All tests were performed at a target impact velocity of 6.7 m/s.

Impactor, upper spine (T01) X-, Y- and Z-axis accelerations and upper, middle and lower rib deflections were recorded during each test. The impactor force was calculated by multiplying the impactor acceleration by its mass. All of the data were digitally filtered using SAE J211 CFC 180.

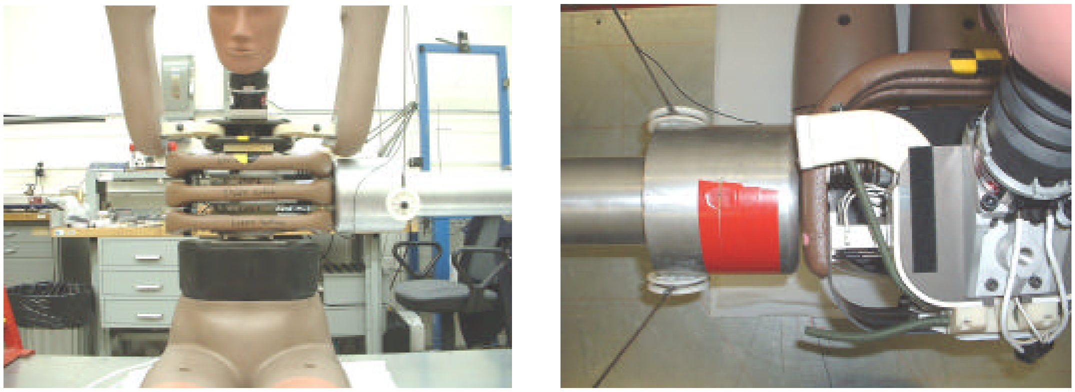


Figure VIII-3. 0° Thoracic Impact Front & Top Views

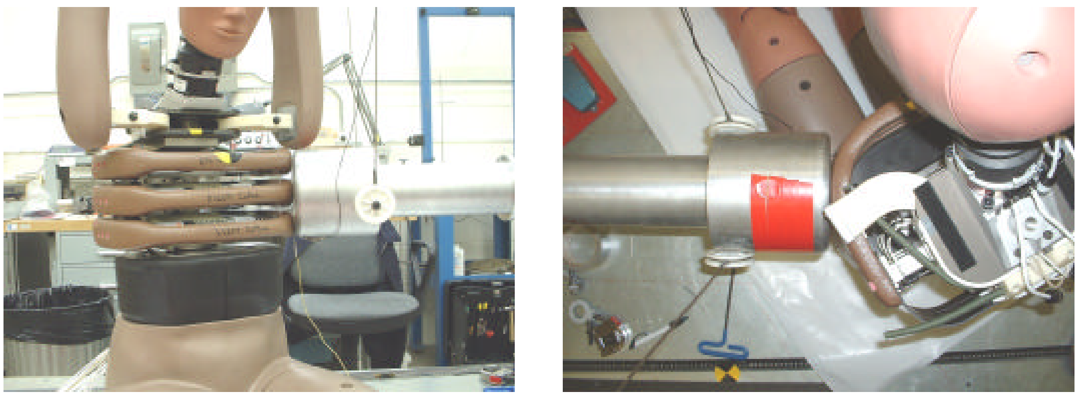


Figure VIII-4. +30° Thoracic Impact Front & Top Views

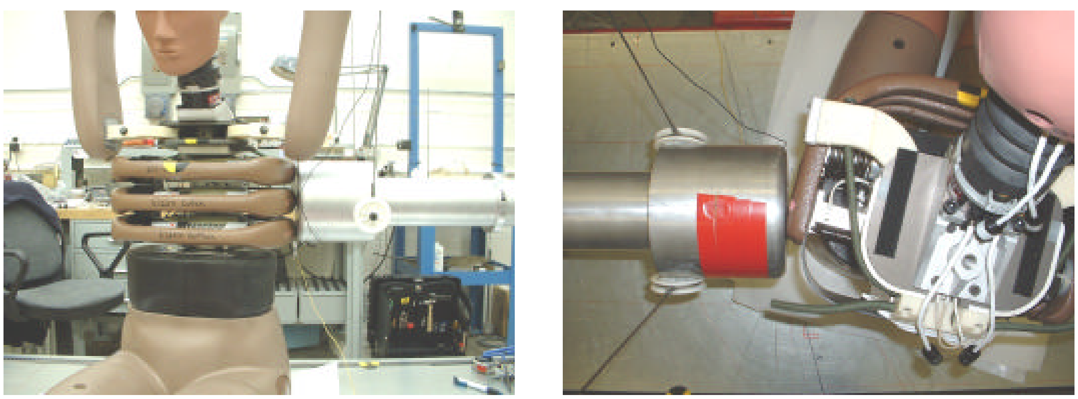


Figure VIII-5. -15° Thoracic Impact Front & Top Views

VII.3.2. Test results

VII.3.2.1. Shoulder response

A summary of the shoulder peak response levels in pendulum impacts is presented in Table VIII-4. Further details from these tests may be found in [18]. The shoulder deflection data indicate that at equal pendulum impact speed, the shoulder's lateral deflection decreases as the anterior impact angle increases.

Table VIII-4. Summary of Oblique Shoulder Impact Results

Impact Angle (Degrees)	Mean Impactor Velocity (m/s)	Mean Max. Y-Component Impactor Force (N)	Mean Y-Component Shoulder-to-Shoulder Deflection @ Max. Force (mm)	Ratio of Deflection Shoulder to Shoulder Relative to 0 Degrees
0	4.43	2639	33.5	1.00
+15	4.43	3129	27.9	0.83
+30	4.43	2592	16.2	0.48

VII.3.2.2. Thorax response

A summary of the results from the oblique thorax impact tests is presented in Table VIII-5. Further details from these tests may be found in [18].

Table VIII-5. Summary of Oblique Thoracic Impact Test Results

Impact Angle (degrees)	Mean Impactor Velocity (m/s)	Mean Max. Impactor Force (N)	Mean Upper Spine (T01) Y-Axis Acceleration (g)	Ratio of TO1 Y-Axis Acceleration Relative to 0 Degrees	Mean Upper Spine (T01) Resultant Acceleration (g)	Mean Rib Deflection (mm)	Ratio of Rib Deflections Relative to 0 Degrees
+30	6.72	10546	33.5	1.08	44.7	-35.9	0.78
+15	6.72	10180	32.0	1.04	32.2	-39.3	0.85
0	6.72	11099	30.9	1.00	31.3	-46.0	1.00
-15	6.72	14123	37.2	1.20	37.3	-49.4	1.17

Maximum impactor force as well as the respective upper spine Y-axis acceleration components are relatively similar at impact angles of 0°, +15° and +30°. However, both of these responses increase substantially for posterior impacts at - 15 degrees pendulum orientation. While the resultant accelerations are similar to each other at + 15, 0 and -15 degrees impacts, they become substantially larger at +30 degrees impactor orientation due a larger contribution by the X-axis vector. In contrast, the rib deflection is lowest at +30 degrees impact. It steadily increases as the impact orientation moves towards pure lateral and into the posterior impact vector orientation.

VIII.4. Discussion

VRTC test data indicate that the ES-2re dummy's impact response exhibits some sensitivity to oblique impacts in these types of pendulum impact tests. The dummy's shoulder assembly becomes stiffer as the impact angle increases in the anterior orientation from a purely lateral impact orientation. In contrast, in the thorax impact tests, the Y-axis acceleration of the thoracic spine at the T01 level increases only minimally as the anterior angle of the impact becomes larger. However, the acceleration becomes substantially larger when the impact is from posterior direction. The effects are opposite for rib deflection. The rib deflections decrease as the anterior impact angle increases from pure lateral and the deflection increases as the angle changes from pure lateral to posterior impact orientation.

Data in test series 1 were processed both by applying FIR and SAE J211 CFC 180 filters to determine the effects on the magnitude of angular sensitivity. While there are some relatively small changes by the two processing methods, on the whole, data processing differences neither measurably change nor affect the trends in the sensitivity of the dummy to oblique pendulum impacts.

The EEVC studied the ES-2 dummy’s impact angle sensitivities and found them, in general, acceptable and comparable to the EuroSID-1 in full body pendulum tests [2]. We have little knowledge about the extent the pendulum based oblique impact sensitivity is relevant to vehicle tests, such as FMVSS 214 and 201. It is reasonable to assume that pendulum type impact sensitivities are far less pronounced and important in vehicle tests, particularly on the driver occupant. Most barrier-based side impact crashes result in the vehicle side structure approaching and impacting the driver occupant primarily with lateral orientation. Accordingly, the driver occupant should experience under those circumstances impacts that are primarily lateral unless the vehicle doors or the occupant compartment side structures are intruded with large angular deformations or ruptures.

Chapter IX. Repeatability and Reproducibility

A dummy's repeatability and reproducibility (R&R) are typically based on component tests and a series of sled tests in which it is attempted to control the impact input as well as the test equipment with the goal of minimizing the external effects on the dummy's response. Component tests are better controlled and thus produce more reliable estimates of the dummy's repeatability and reproducibility at component and subsystem levels than is possible in sled and vehicle tests. Sled tests on the other hand offer a method to efficiently test the dummy as a complete system in an environment much like a vehicle test. This report includes data from component and sled tests of two sets of ES-2re dummies. Component tests were performed at MGA Research Inc. using dummies S/N 9 and S/N 10, and component and sled tests at VRTC with dummies S/N 70 and S/N 71.

Standard measure of repeatability, using methodology developed by ISO/TC22/SC12/WG5, was employed for this assessment. Repeatability of the crash test dummy is defined as the ability of the dummy to reproduce the same response given identical stimulus in repeated tests [25]. Reproducibility is defined as the ability of multiple dummies of the same design to reproduce the same response given identical stimulus in repeated tests. Repeatability/reproducibility of a dummy is assessed by CV (percent coefficient of variation) computations. A CV is expressed as the standard deviation divided by the mean of the tested population and multiplied by one hundred. For repeatability purposes a dummy attaining a CV of 0-5% is rated excellent, >5-8% good, >8-10% marginal, and above 10 unacceptable. The rating for reproducibility takes into account the cumulative variability of two or more dummies. Thus corresponding rating values for reproducibility are 0% to 6% for excellent, >6 to 11% for good, >11 to 15% for marginal and >15% not acceptable.

IX.1. Repeatability and reproducibility of ES-2re dummies in component tests

Tables IX-1 through IX-3 list the impact response averages, calculated standard deviations and CVs of test results that were collected in dummy certification tests using procedures referenced in the ES-2 Users Manual, February 2002 [17]. The certification tests and results are more fully described in Chapter V of this technical report.

The dummy's initial repeatability and reproducibility assessments in these component tests were based on test responses of dummies S/N 9 and S/N 10. They included head, neck, shoulder, thorax, abdomen, lumbar spine and pelvis impact responses. The tests were performed over a period of approximately two years at the MGA Research Inc. as part of routine calibrations each time the dummy was used in crash tests. Results from these tests are summarized in Tables IX-1 and IX-2 for dummies S/N 9 and S/N 10, respectively. In early part of 2004, VRTC conducted a systematic repeatability and reproducibility study as part of determining how well do the newly acquired ES-2re dummies S/N 70 and 71 comply with the certification requirements. Results from these tests are shown in Table IX-3.

Table IX-1 Repeatability of Component and Sub-system Impact Responses of ES-2re S/N 9 Crash Test Dummy in MGA tests

Component	Type of test	Average	Stand deviation	CV%
Head drop	Peak resultant avg acceleration -g	138.78	5.59	4.02
Neck –pendulum test	Max .flexion angle deg.	57.82	1.46	2.53
	Time of max. flexion angle -ms	60.28	2.71	4.49
Shoulder –pendulum impact	Max. resultant acceleration -g	9.68	0.35	3.61
Upper rib-probe impact 4m/s	Max displacement -mm	49.56	1.30	2.62
Middle rib-probe impact 4m/s	Max displacement -mm	49.06	1.28	2.61
Lower rib-probe impact 4m/s	Max displacement -mm	48.54	0.90	1.86
Abdomen probe impact 4m/s	Max. abdominal force -.kN	2.36	0.08	3.37
Lumbar spine-pendulum Impact - 6.05.m/s	Max flexion angle deg	50.73	2.13	4.20
Pelvis pendulum impact – 4.3 m/s	Max pubic force -.kN	1.31	0.06	3.83

Table IX-2 Repeatability of Component and Sub-system Impact Responses of ES-2re S/N 10 Crash Test Dummy in MGA tests

Component	Type of test	Average	Stand deviation	CV%
Head drop	Peak resultant avg acceleration -g	139.86	6.26	4.47
Neck –pendulum test	Max .flexion angle deg.	57.36	0.70	1.22
	Time of max. flexion angle -ms	58.73	1.56	2.66
Shoulder – pendulum impact	Max. resultant acceleration -g	10.13	0.29	2.83
Upper rib-probe impact 4m/s	Max displacement - mm	49.80	0.93	1.86
Middle rib-probe impact 4m/s	Max displacement - mm	49.47	0.72	1.46
Lower rib-probe impact 4m/s	Max displacement - mm	50.11	0.37	0.74
Abdomen probe impact 4m/s	Max abdominal force -.kN	2,48	0.07	2.66
Lumbar spine-pend. Impact - 6.05.m/s	Max flexion angle deg	51.00	2.53	4.96
Pelvis pendulum impact – 4.3 m/s	Max pubic force - .kN	1.40	0.09	6.24

Reproducibility in component and subsystem tests was established by calculating cumulative responses of the VRTC dummies S/N 70 and S/N 71. Reproducibility of dummies S/N 9 and S/N 10 was not calculated, because their calibration data represent measurements over a long period of time with intermittent exposures of the dummies in vehicle and other types of crash tests.

Table IX-3 shows a summary of the VRTC component and subsystems test results and analysis of repeatability and reproducibility by the CV measure. The data indicate that the repeatability and reproducibility of the ES-2re dummies at the component and subsystem level are in the “excellent” and “good” range, except for maximum shoulder acceleration response of dummy 071, which is in the “marginal” range.

Table IX-3. Repeatability and Reproducibility of Component and Sub-system Impact Responses of ES-2re S/N 70 and 71 Crash Test Dummies in VRTC Tests

	S/N 70			S/N 71			S/N 70 & 71 Combined		
	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)
Head									
Peak Resultant Acceleration (g)	146.3	1.6	**1.1**	132.3	2.1	**1.6**	139.3	7.6	**5.4**
Neck									
Flexion Angle (deg)	55.0	.5	**.9**	54.4	.3	**.5**	54.7	.5	**.9**
Time of Flexion Angle (ms)	58.10	1.36	**2.3**	57.59	1.56	**2.7**	57.84	1.40	**2.4**
A Angle (deg)	35.2	.2	**.7**	34.8	.2	**.5**	35.0	.3	**.9**
Time of A Angle (ms)	55.50	1.21	**2.2**	55.11	.75	**1.4**	55.31	.97	**1.8**
B Angle (deg)	32.3	.2	**.7**	31.9	.1	**.5**	32.1	.3	**.9**
Time of B Angle (ms)	56.80	.91	**1.6**	55.28	1.44	**2.6**	56.04	1.39	**2.5**
Shoulder									
Impactor Acceleration (g)	11.4	.3	**2.7**	10.8	1.0	**9.3**	11.1	.8	**6.9**
Thorax									
Upper Rib Def. - 4.0 m/s (mm)	47.5	.7	**1.5**	48.9	1.9	**3.9**	48.2	1.5	**3.1**
Middle Rib Def. - 4.0 m/s (mm)	49.3	.2	**.3**	49.2	.1	**.3**	49.3	.1	**.3**
Lower Rib Def. - 4.0 m/s (mm)	49.5	.2	**.4**	49.2	.0	**0.0**	49.4	.2	**.5**
Abdomen									
Maximum Impactor Force (N)	4712	101	**2.1**	4719	93	**2.0**	4716	92	**1.9**
Time of Max. Impactor Force (ms)	12.57	.09	**.7**	12.44	.15	**1.2**	12.50	.13	**1.1**
Maximum Abdomen Force (N)	2248	155	**6.9**	2420	91	**3.8**	2334	150	**6.4**
Time of Max. Abdomen Force (ms)	11.86	.2	**1.7**	12.06	.12	**1.0**	11.96	.19	**1.6**
Lumbar Spine									
Flexion Angle (deg)	48.0	.4	**.8**	48.2	.7	**1.4**	48.1	.5	**1.1**
Time of Flexion Angle (ms)	46.12	.77	**1.7**	46.00	.88	**1.9**	46.06	.79	**1.7**
A Angle (deg)	32.2	.3	**.9**	32.8	.5	**1.5**	32.5	.5	**1.5**
Time of A Angle (ms)	46.06	.66	**1.4**	46.28	1.04	**2.3**	46.17	.83	**1.8**
B Angle (deg)	29.7	.1	**.3**	29.7	.4	**1.3**	29.7	.3	**.9**
Time of B Angle (ms)	45.44	..81	**1.8**	45.19	.30	**.7**	45.32	.59	**1.3**
Pelvis									
Maximum Impactor Force (N)	5153	181	**3.5**	5277	71	**1.3**	5215	145	**2.8**
Time of Max. Impactor Force (ms)	13.92	.43	**3.1**	14.02	.61	**4.4**	13.97	.50	**3.6**
Max. Pubic Symphysis Force (N)	1415	57	**4.0**	1380	15	**1.1**	1397	43	**3.1**
Time of Max. Pubic Symphysis Force (ms)	15.13	.52	**3.4**	14.61	.67	**4.6**	14.87	.63	**4.2**

IX.2. Repeatability and Reproducibility of the ES-2re Dummies in Sled Tests

The sled tests referenced in this section are more fully described in Chapter VI. Repeatability and reproducibility (R&R) data analysis was performed only on the VRTC set of sled test data, since the MGA data was not in sufficient quantity to be used for such purpose. As noted in Chapter VI, VRTC subjected the two newly acquired ES-2re dummies (S/N 70 and -71) to a series of sled tests to determine the R&R of their impact responses [20]. Each dummy was exposed to five repeats in two types of sled test conditions:

1) Flat rigid wall impact at 6.7 m/s (12.7 g peak, 80 ms duration), and
2) Rigid wall with protruding abdominal block impact at 6.7 m/s (12.7 g peak, 80 ms duration)

The methodology to evaluate the dummies for repeatability and reproducibility is the same as for component tests.

IX.2.1 Sled buck description and test procedure

The sled buck test procedures and the impact environment used by VRTC to develop the R&R data are the same as described in Chapter VI, Section VI.3.

IX.2.1.1 Test Results

IX.2.1.1.1. Flat wall test series

Assessment of ES-2re S/N 70 and 71 dummies in terms of CV values for repeatability and reproducibility in flat wall sled impact tests are shown in Table IX-4. The VRTC Technical Report on ES-2re R&R in the sled test environment contains a complete summary of the peak responses of both dummies (Appendix B, Table B1 [20]) and the response-time traces for each individual sensor (Appendix B, Figures B.1 through B.22.b [20]).

Table IX-4. CV Values for Flat Wall Sled Test Responses

		Dummy SN	070	071	both
Location	**Measurement**	**Direction**	%CV	%CV	% CV
Head CG	Acceleration	Y	4.2	3.0	8.4
		Z	1.0	1.9	3.6
		Resultant	1.0	1.9	6.7
	HIC-36	Resultant	2.8	3.2	3.4
Head	Displacement (Front Camera)	Lateral	3.5	2.3	3.7
		Vertical	3.4	4.5	6.8
		time	3.3	2.1	2.8
Upper Neck	Force	Y	2.1	1.9	2.4
		Z	1.9	1.9	4.6
	Moment	+X	8.2	3.0	6.3
		-X	7.9	1.5	8.3
		-Y	3.3	5.7	4.5
		+Z	4.2	4.3	4.2
Shoulder	Force	Y	5.9	3.4	9.8
T1	Acceleration	Y	1.5	2.4	5.7
		Resultant	4.8	2.2	5.0
T12	Acceleration	Y	4.0	2.8	5.7
		Resultant	3.8	2.8	5.3
Upper Rib	Displacement	Y	1.9	2.2	9.0
Middle Rib	Displacement	Y	0.7	1.3	5.0
Lower Rib	Displacement	Y	0.9	0.9	2.6
Abdomen-Front	Force	Y	7.8	4.6	7.0
Abdomen-Center	Force	Y	7.4	4.8	6.4
Abdomen-Rear	Force	Y	6.9	4.6	9.4
Abdomen-Sum	Force	Y	6.0	4.5	5.9
Lumbar	Force	Y	14.8	10.0	17.5
	Moment	+X	3.2	1.8	4.1
Pubic Symphysis	Force	Y	4.2	3.3	4.7
Pelvis	Acceleration	Y	7.3	4.8	5.8
		Resultant	3.8	4.7	4.1
Sled	Acceleration	X	0.4	0.4	0.3
Sled	Velocity	X	0.2	0.2	0.2

The responses in the flat wall tests displayed excellent and good repeatability, except for the lumbar Y (shear) force of dummy S/N 70 falling outside the CV marginal boundary at 14.8%. The elevated CV value for dummy S/N 70 lumbar Y force was responsible for an unacceptable reproducibility assessment of lumbar Y force, at a CV of 17.5%. While these CV values are higher than the allowable limit, the elevated measurement shows no indication of having an effect on either the magnitude or the variability of the impact responses of adjacent body segments such as pubic symphysis, the abdomen and T12.

IX.2.2.1.1.2 Abdomen offset test series

Assessment of ES-2re S/N 70 and S/N 71 dummies in terms of CV values for repeatability and reproducibility in abdomen-offset impacts are shown in Table IX-5.

Appendix C of the associated VRTC report contains a complete summary of the peak responses of both dummies in the abdomen offset test condition (Table C1 [20]) and the response-time traces for each individual sensor (Figures C.1 through C.20.b [20]). Upon thorough review of the response traces after the test series was completed, it was noted that the first test in the series (test #S040109-1), with dummy S/N 70, exhibited responses that were somewhat different from the responses observed in the remaining four tests. When compared to the subsequent four tests, the first test had significantly lower abdominal and lumbar loads and larger rib displacements (Appendix C, Figures C.10 through .18 [20]). The data for test #S040109-1 indicate that contact with the abdominal offset block was initiated favoring more the proximity of the lower rib than in the subsequent four tests, and therefore, that test had to be excluded from the statistic.

The abdomen offset sled tests, as a whole, yielded excellent and repeatable and reproducible response levels, except for one unacceptable lumbar moment response at the CV level of 16.7, which is 1.7% above the marginal limit. While this CV value is higher than the allowable limit, the elevated response does not have a measurable effect either on the magnitude of the loading or the variability of the responses of adjacent body segments, such as pubic symphysis, the abdomen and T12.

Table IX-5. %CV Values for Four Abdomen Offset Sled Test Responses

Dummy SN			070	071	both
Location	**Measurement**	**Direction**	%CV	%CV	% CV
Head CG	Acceleration	Y	1.6	4.6	4.3
		Z	4.2	6.9	5.6
		Resultant	2.7	7.5	5.7
	HIC-36	Resultant	3.2	5.9	6.0
Head	Displacement (Front Camera)	Lateral	1.1	2.2	1.7
		Vertical	3.4	3.6	4.7
Upper Neck	Force	Y	1.2	4.4	3.7
		Z	3.7	7.6	5.7
	Moment	+X	1.2	3.0	3.9
		-X	1.2	0.7	1.6
Shoulder	Force	Y	1.3	3.2	2.7
T1	Acceleration	Y	1.4	4.8	3.6
		Resultant	1.3	4.8	3.5
T12	Acceleration	Y	0.4	1.2	2.5
		Resultant	0.4	1.1	2.8
Upper Rib	Displacement	Y	2.7	4.4	9.5
Middle Rib	Displacement	Y	3.3	5.9	4.5
Lower Rib	Displacement	Y	2.4	5.9	11.3
Abdomen-Front	Force	Y	1.6	4.9	9.5
Abdomen-Center	Force	Y	2.1	6.0	7.6
Abdomen-Rear	Force	Y	3.1	5.7	5.8
Abdomen-Sum	Force	Y	1.9	5.5	7.3
Lumbar	Force	Y	2.6	1.0	5.7
	Moment	+X	2.6	6.7	16.7
	Moment	-X	1.9	2.7	7.1
Pubic Symphysis	Force	Y	3.6	5.1	4.1
Pelvis	Acceleration	Y	2.1	2.7	4.2
		Resultant	0.6	2.4	3.2
Sled	Acceleration	X	0.2	0.2	0.1
Sled	Velocity	X	0.2	0.2	0.2

IX.3. Conclusions

Repeatability of the two ES-2re S/N 9 and S/N 10 dummies by the measure of component responses in calibration type tests are in the “excellent” range except for the maximum pubic force response, which is in the “good” range.

Repeatability and reproducibility of the ES-2re S/N 70 and S/N 71 dummies at the component and subsystem levels are in the “excellent” and “good” range, except for maximum shoulder acceleration response of dummy 071, which is in the “marginal” range

Repeatability and reproducibility of dummies S/N 70 and S/N 71 in flat wall and offset abdomen sled tests, in which the dummies were exposed to severe loading conditions, resulted in excellent and good response levels. The R&R analysis indicates that the dummies were able to generate responses that were at better than acceptable level for nearly every anticipated injury assessment measure.

The only value that did not meet fully the acceptability criteria for repeatability and reproducibility in flat wall sled tests was the lumbar shear force. However, this response did not seem to have a measurable effect on either the magnitude or the variability of the adjacent sensor responses.

The sole measurement in the abdomen-offset tests not meeting the acceptable criteria was the reproducibility of the lumbar moment response at the CV level of 16.7. This is only 1.7% above the acceptability limit of 15%. While this CV value is higher than the allowable limit, the elevated measurement shows no indication of having affected either the magnitude or the variability of the impact responses of adjacent body segments.

X Full Scale Crash Test Performance

Since 1997, NHTSA has acquired considerable full scale crash test experience with the European side impact dummy: 8 crash tests with the Eurosid-1, 37 crash tests with ES-2, and 13 crash tests with the ES-2re . This section highlights the test matrices and main results comparing the performance of ES-2 and ES-2re dummies. Detailed dummy and vehicle data from all the tests are available from the NHTSA website through the specification of the either the unique test numbers provided below or the vehicle make and model (http://www-nrd.nhtsa.dot.gov/database/nrd-11/veh_db.html). Test results have also been disseminated via publications [26, 27, and 28] and public presentation made in various forums and others accessible from the NHTSA website:

- http://www-nrd.nhtsa.dot.gov/departments/nrd-01/presentations/presentations.html, "Status of ES-2 Research at NHTSA" ,U.N./ECE/GRSP Meeting, Switzerland, December 2002.
- http://www-nrd.nhtsa.dot.gov/pdf/nrd-01/SAE/SAE2002/RSamaha_SAE2K2.pdf, "ES-2 Crash Test Performance", SAE Government Industry Meeting, April 2002.
- http://www-nrd.nhtsa.dot.gov/pdf/nrd-01/SAE/SAE2001/Samaha.PDF **, "**NHTSA Side Crash Protection Research", SAE Government/Industry Meeting, May 2001.

X.1. EuroSID-1 Testing

To obtain an initial assessment of the level of safety performance of vehicles for both the U.S. and European Union regulations, NHTSA performed in summer of 1997 a series of eight crash tests of FMVSS 214 compliant vehicles using the EU 96/EC/27 test procedure and the Eurosid-1 dummy [26]. The test matrix is shown in Table X-1.

Table X-1 Reference [26] "Table 3. FMVSS 214/EU 96/27/EC Test Matrix**"**

Test #	Vehicle		FMVSS 214 test	Side NCAP
9081	1996 Ford Taurus*	4-Dr	1996	Yes
2719	1995 Volvo 850	SW	1995	No
2706	1997 Nissan Sentra	4-Dr	1996	Yes
2705	1997 Hyundai Sonata	4-Dr	1996	Yes
2738	1997 Ford Mustang	2-Dr	1996	Yes
2752	1997 Lexus SC300	2-Dr	1995	No
2660	1995 Geo Metro	2-Dr	1996	No
2752	1997 Mitsubishi Eclipse	2-Dr	1996	No

*Ford Motor Company performed the EU test of the 1996 Taurus.

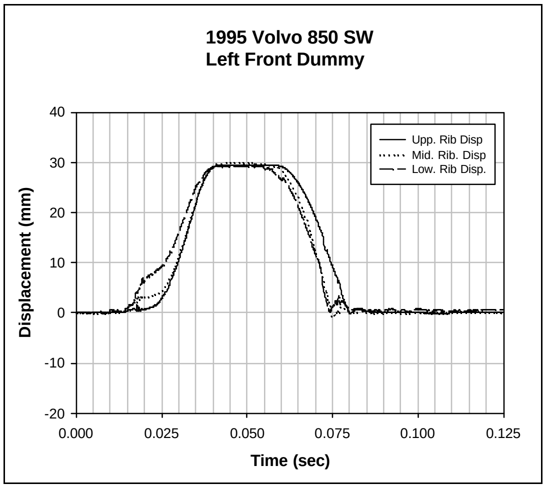


Figure X-1. EuroSID-1 Rib deflection

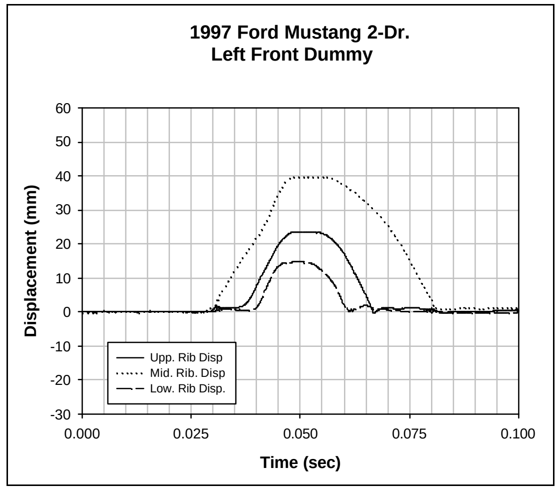


Figure X-2. EuroSID-1 Rib deflection

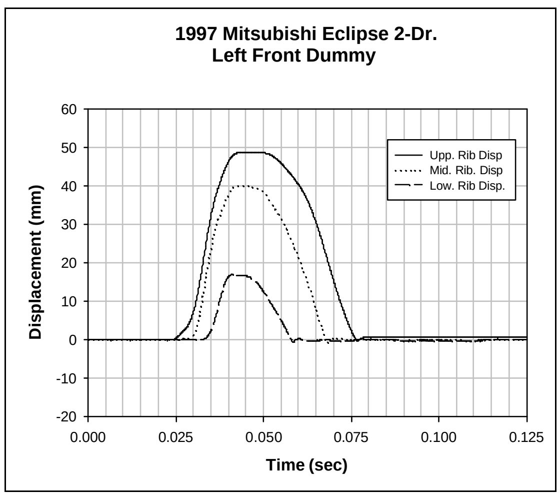


Figure X-3. EuroSID-1 Rib deflection

The main finding relative to the Eurosid-1 dummy performance from the 1997 tests was that plateaus, termed “flat-top” behavior, were present in the dummy rib deflection data for all the tests, examples shown in Figures X-1 through -3. As stated in Chapter II.1, rib deflection flat tops were deemed to be of concern, especially at low levels of deflection, as they can be an indication that the rib deflection mechanism is binding and thus the thorax is not responding correctly to the load from the intruding side structure. Accordingly, the resulting peak deflections, which are based on the measured rib deflection, would be of questionable usefulness as injury indicators.

X.1.1 Testing the upgraded EuroSID-1 in 2000

The upgrades to EuroSID-1, introduced in early 2000, considered three varieties of rib designs intended to reduce friction in the rib guide bearings system:

- Coated piston: Standard EuroSID-1 ribs with PTFE (Poly-Tetra-Fluoro-Ethylene) coating, a polymer known for its extreme low friction properties
- Ball bearing: Guide system with spherical bearings
- Needle bearing: Guide system with linear needle bearings

To assess which rib design best addressed the flat top anomaly, NHTSA performed a series of a high mass impactor tests with the ES-2 prototype dummy fitted with each of the three proposed ribs designs. The high mass impactor test was designed to simulate the loading conditions on the dummy similar to those seen in full-scale vehicle tests [27]. The high mass impactor is a Part 581 Bumper Testing Pendulum ballasted to 907 kg that is preloaded with linear compression springs attached between the pendulum and the test frame to increase the impact speed. The impactor face, covered with thick plywood sheet, was targeted to engage the abdomen, thorax and arm of the dummy just below the arm/shoulder interface joint. Impact angles were -10 degrees (rearward oblique), +10 and +20 degrees (frontal oblique), and a lateral impact at zero degrees. The impact speed was approximately 18.3 km/hr.

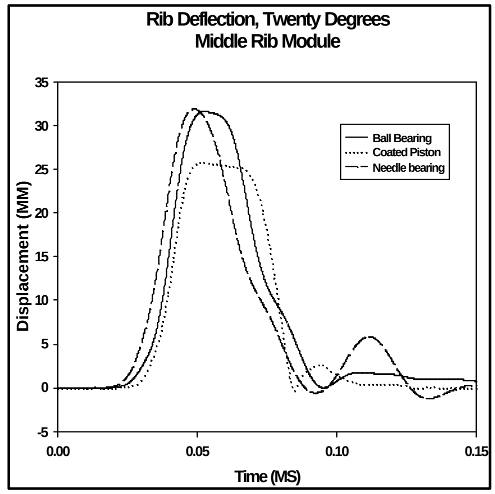


Figure X-4

Amongst the three rib guide designs, the needle bearing rib design was the only one that produced no rib deflection flat top behavior in the high mass impactor tests (example shown in Figure X-4). The EuroSID-1 dummy with this upgrade became the prototype ES-2.

X.2. ES-2 prototype in Full Scale crash tests

In summer of 2000, NHTSA performed six full-scale crash tests with both front and rear seated ES-2 prototype dummies (Table X-2). The tests denoted with "**" are baseline responses of the EuroSID-1 dummy performed in 1997 in accordance with the EU 96/EC/27 side impact procedure. They are compared with the prototype ES-2 responses in repeat test conditions. The test matrix also included two vehicle tests in the FMVSS 214 configuration and two tests per US Side NCAP procedure. The latter was chosen to provide a higher-severity loading environment for the ES-2 (the Chevy Cavalier and the Pontiac Grand Am vehicles were selected for this purpose because of their marginal performance in the US Side NCAP tests with the U.S. SID dummy).

Table X-2. [Reference [28] "Table 3. Reference Full Scale Test Matrix"]

Test #	Vehicle	Dummy	Test configuration	Speed (km/h)
9081	96 Taurus- 4dr**	Eurosid-1	EU Side	48.3
3445	96 Taurus- 4dr	ES-2*	EU Side	49.2
2660	95 Metro- 3dr**	Eurosid-1	EU Side	50.3
3444	96 Metro- 3dr	ES-2*	EU Side	50.5
3482	96 Taurus- 4dr	ES-2*	FMVSS 214	53.3
3522	96 Taurus- 4dr	ES-2*	FMVSS 214	52.3
3523	98 Chevy Cavalier- 4dr	ES-2*	US Side NCAP	61.6
3527	2000 Grand Am- 2dr	ES-2*	US Side NCAP	62.1

*prototype

X.2.1. Rib deflection response

For FMVSS 214 tests with the ES-2 prototype, there was no incidence of flat top behavior in any of the ES-2 measured rib deflections, e.g. in Figures X-5 and X-6. In contrast, the Side NCAP tests of the Chevy Cavalier showed the driver upper rib deflection "flat topping" at 51.4 mm (Figure X-7). As a result, the deflection response of the upper rib module was further investigated by performing additional rib certification drop tests at higher impact velocities of 4.2, 4.5, and 4.75 m/s. A slight amount of flat top response was observed in the 4.75 m/s impact at a deflection level of 55 mm (Figure X-8). A repeat drop test at the high impact velocity indicated that the maximum available space for the ribs to deflect is around 55 mm. The Cavalier driver upper rib deflection was in the vicinity of that range.

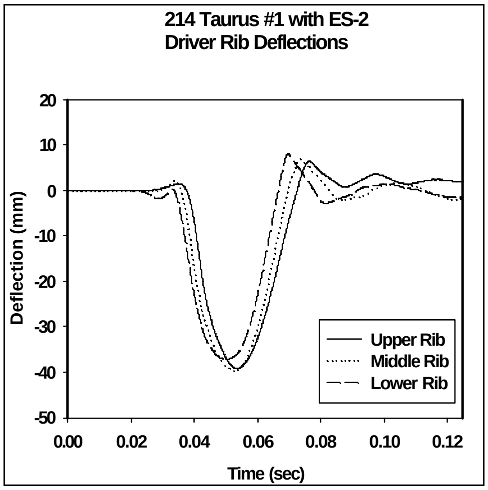


Figure X-5

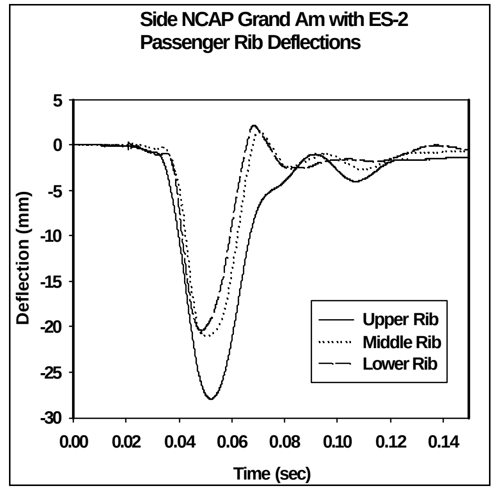


Figure X-6

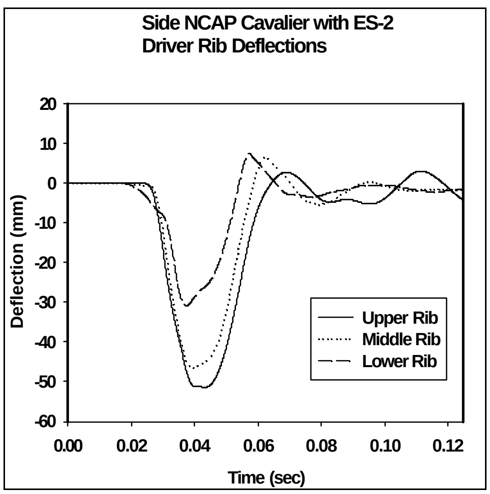


Figure X-7

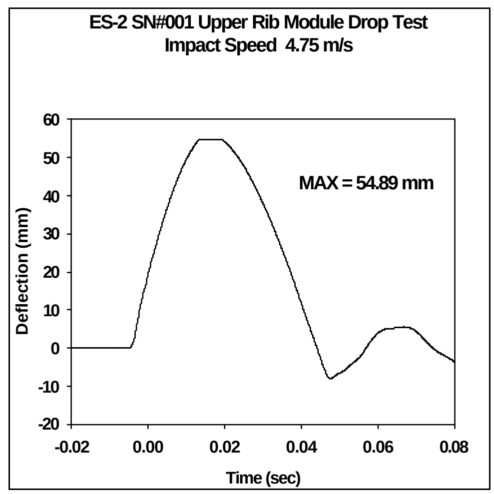


Figure X-8

X.2.2. Pubic Symphysis Loads: One of the issues raised with Eurosid-1 were spikes in the pubic symphysis force (PSF) measurements associated with knee-to-knee impact. To improve leg interactions, a high mass flesh system was introduced in the ES-2 legs. A new attachment in the pelvis, to increase the range of upper leg abduction, and rubber buffers were also introduced in the ES-2 upgrade.

To investigate the occurrence of knee-to-knee contact and the resulting effect on pubic loads, the femur loads from this test series with the prototype ES-2 were examined for oscillations in the X-, Y-, and Z- axis components around the time of increasing but opposite direction load components that were observed in the left and right lateral femurs. It was assumed that the knee-to-knee contact could lead to an oscillatory/ringing effect that travels up the femurs and could result into increased levels of PSF. Presuming that the femur load oscillations are an indication of knee-to-knee contact, the pubic symphysis

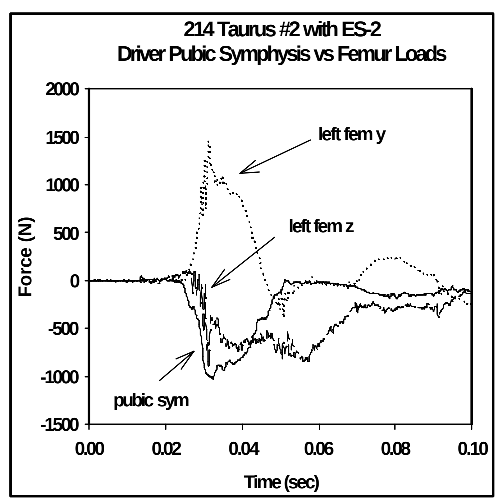


Figure X-9

loads were then examined for increased levels and spikes around the time of knee-to-knee contact.
The data in the full scale tests suggested that knee-to-knee contact in the ES-2 prototype dummy, even in evidence of some short duration spiking, has little or no effect on the level of pubic symphysis loads; e.g. over plots of the femur loads in Figures X-9, -10, and -11 show only a minor increase of the PSF peak levels at the time of knee-to-knee contact.

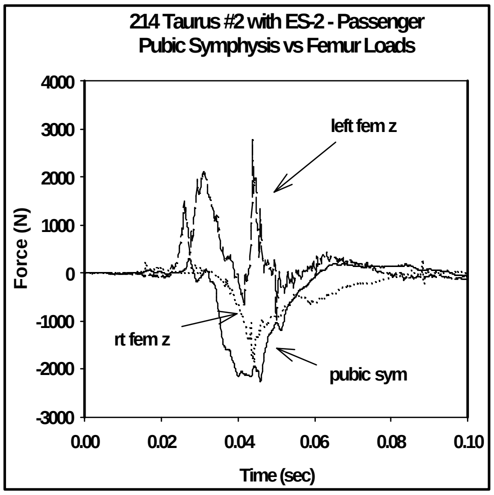


Figure X-10

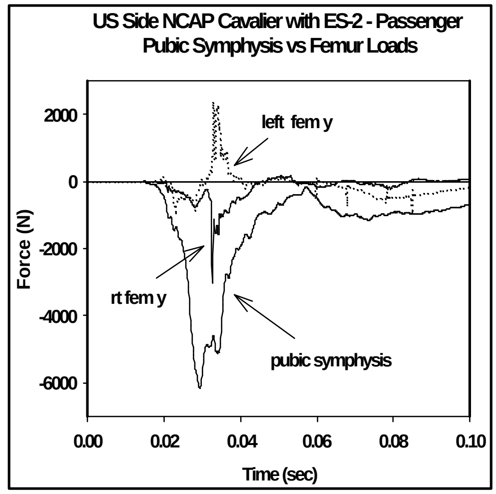


Figure X-11

Some of the driver dummy peak responses from the 2000 ES-2 prototype crash test series are shown in Tables X-3 and X-4. The test conditions, the dummy, and the vehicle in these tables can be cross-referenced by test number from Table X-2.

Table X-3. [Reference [28] "Table A1. Full Scale Driver Test Results - Rib Deflections"]

vehicle/test	**Max rib defl**	**up rib defl CFC 180**	**mid rib defl CFC 180**	**low rib defl CFC 180**
	(mm)	**(mm)**	**(mm)**	**(mm)**
EU Taurus/EUROSID-1 (#9081)	40	30	38	40
EU Taurus/ES-2 (#3445)	51	38	47	51
214 Taurus #1/ES-2 (#3482)	40	39	40	37
214 Taurus #2/ES-2 (#3522)	35	35	33	24
EU Metro/EUROSID-1 (#2660)	44	44	38	28
EU Metro/ES-2 (#3444)	48	48	44	34
NCAP Cavalier/ES-2 (#3523)	51	51	47	31
NCAP Grand Am/ES-2 (#3527)	51	51	29	16

Table X-4 [Reference [28] "Table A2. Full Scale Driver Test Results - Shoulder, Abdomen, Lower Spine, Pubic Symphysis, and Left Femur Loads"]

vehicle/test	Sh y	sh z	back pl x	back pl y	max abdomen	T12 y	pubic symphysis	left fem y	left fem z
	(N)	(N)	CFC 600 (N)	CFC 600 (N)	CFC 600 (N)	CFC 600 (N)	CFC 600 (N)	CFC 600 (N)	CFC 600 (N)
EU Taurus/EUROSID-1 (#9081)	na	na	na	na	1131	na	-2196	na	na
EU Taurus/ES-2 (#3445)	309	543	179	-316	1740	1770	-917	1267	852
214 Taurus #1/ES-2 (#3482)	518	1288	433	-511	1551	2194	-927	1407	-828
214 Taurus #2/ES-2 (#3522)	771	1412	399	734	2513	2618	-1020	1409	-840
EU Metro/EUROSID-1 (#2660)	na	na	na	na	1518	na	-4158	na	na
EU Metro/ES-2 (#3444)	824	735	241	-450	1344	1369	-3512	1706	-1281
NCAP Cavalier/ES-2 (#3523)	991	1275	1168	889	2536	3041	-1620	-2558	1805
NCAP Grand Am/ES-2 (#3527)	4091	600	265	-658	2587	3654	-1786	-1560	1309

Note: sh is shoulder, back pl is back plate, T12 is lower spine, and fem is femur; na is not available

X-2.3. Conclusions

Overall results from limited full-scale crash tests with the ES-2 prototype dummy and its comparison with the EuroSID-1 lead to the following conclusions:

- ES-2 modifications appear to have addressed rib binding which is one mechanism of rib deflection flat top response in the Eurosid-1. Rib deflection flat top response was not present in the FMVSS 214 tests. Also, the flat top response due to rib binding was not found in subsequent US Side NCAP and additional FMVSS 214 tests, described in section X.3;
- ES-2 back plate loads were small when compared with other forces acting on the dummy;
- Knee-to-knee contact in the ES-2 had little or no effect on pubic symphysis loads.

X.3. ES-2 TESTING in 2001, 2002, and 2003

X.3.1 Overview and Test Matrices

Results from initial components, sled, and full scale crash testing of the ES-2 upgrade prior to 2001 by NHTSA showed promise that concerns with the Eurosid-1 mechanical deficiencies have been addressed. Overall, the ES-2 prototype responses also showed good repeatability in component and limited sled tests as discussed in section IX. The agency continued to evaluate the ES-2 dummy in subsequent years as summarized below:

A. Higher severity testing: FMVSS 214 tests with a higher and heavier movable deformable barrier (MDB) or an F150 pickup as impactor, and FMVSS 201P side impact pole tests to: 1) assess the durability of the ES-2, 2) further evaluate the mechanical performance of the ES-2 with the new linear bearing rib guides systems and provide data on ES-2 and ES-2 re head and neck responses, and 3) investigate concerns with dummy's shoulder interaction kinematics with impacted structures;

B. Fleet performance testing: FMVSS 214, US side NCAP, and FMVSS 201P tests with relevant vehicle models, including side air bag equipped models, to provide data on fleet performance, and to further evaluate the mechanical performance of the ES-2 re in comparison with the ES-2;

C. Oblique side impact pole testing: Test procedure development, dummy and restraint system performance evaluation, dummy and test procedure repeatability, and seating procedure evaluation tests.

The vehicles and test configuration matrices are presented in Tables X-3.1.1-3.1.9. The ES-2 with rib extension retrofit denoted as ES-2re is shown in shaded highlight. The MDB impactor referenced in Table X-3.1.1 is the Institute of Highway Safety (IIHS) Movable Deformable Barrier version 3.0 shown in Figure X-3.1.1 [29].

Table X-3.1.1. High Severity Movable Deformable Barrier (MDB) and Vehicle-to-Vehicle Crash Tests

Test #	Vehicle	Test Procedure	ES-2 Type	Impactor
3668	1999 Nissan Maxima	214 speed/angle	STD*	IIHS MDB
3669	1999 Cadillac Deville	214 speed/angle	STD	IIHS MDB
3755	1999 Cadillac Deville	214 speed/angle	STD	Ford F150
4086	1999 Cadillac Deville	Side NCAP	STD	IIHS MDB
4094	1999 Cadillac Deville	Side NCAP	STD	Ford F150
3679	1999 Geo Prizm	214 speed/angle	STD	IIHS MDB
3756	1999 Geo Prizm	214 speed/angle	STD	Ford F150
4482	1999 Geo Prizm	214 speed/angle	re	Ford F150

***STD=ES-2 without rib extension**

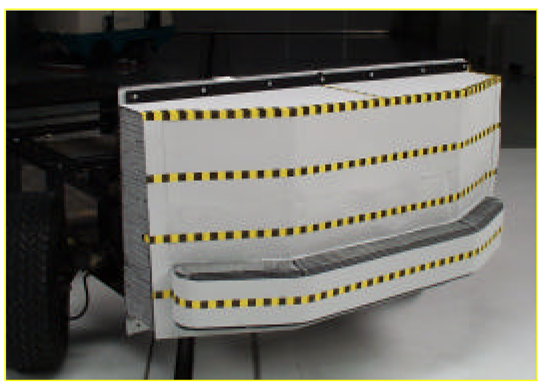


Figure X-3.1.3. IIHS MDB Version 3.0

Table X-3.1.2 FMVSS 201P Pole Tests– Dummy Evaluation

Test #	Vehicle	Test Procedure	ES-2 Type	Airbag
3708	2001 Saturn	201P	STD	NONE
3740	2001 Saturn	201P	STD	CURTAIN
3703	1999 Nissan Maxima	201P	STD	NONE
3707	1999 Nissan Maxima	201P	STD	COMBO

Table X-3.1.3. US Side NCAP Tests

Test #	Vehicle	ES-2 Type	Airbag
3799	2001 Ford Focus	STD	NONE
4456	2001 Ford Focus	re	NONE
3800	2002 Ford Escape	STD	NONE
3803	2002 Chevrolet Impala	STD	COMBO
4380	2002 Chevrolet Impala	re	NONE
3819	2001 Buick LeSabre	STD	THORAX
3875	2002 Honda Odyssey	STD	THORAX
3899	2002 Toyota Tundra	STD	NONE
4097	2003 Toyota Corolla	STD	NONE
4455	2003 Toyota Corolla	re	NONE

Table X-3.1.4. FMVSS 201P Pole Tests – Fleet Performance

Test #	Vehicle	Test Procedure	ES-2 Type	Airbag
3820	1999 Volvo S80	201P	STD	CURTAIN, THORAX
3802	1999 Mercury Cougar	201P	STD	COMBO
3818	1999 Saab 9-5	201P	STD	COMBO
3845	1999 Ford Windstar	201P	STD	COMBO
3898	2002 Ford Explorer	201P	STD	CURTAIN

Table X-3.1.5. FMVSS 214 Tests

Test #	Vehicle	ES-2 Type	Airbag
4547	2001 Ford Focus	re	NONE
4551	2002 Chevrolet Impala	re	NONE
4862	2004 Honda Accord	re	CURTAIN, THORAX

Table X-3.1.6. Oblique Pole Impact Configuration

Test #	Vehicle	Test Procedure	ES-2 Type	ATD Position	Impactor	Impactor Orienta-tion	Airbag
4246	2001 Saturn	Oblique Pole	STD	201 Seating Position	10″ pole	75°	NONE
4313	2001 Saturn	Oblique Pole	STD	201 Seating Position	10″ pole	75°	CURTAIN
4285	1999 Nissan Maxima	Oblique Pole	STD	201 Seating Position	10″ pole	75°	NONE
4284	1999 Nissan Maxima	Oblique Pole	STD	201 Seating Position	10″ pole	75°	COMBO

Table X-3.1.7. Oblique Pole Impact Configuration for Dummy & Restraint System Performance

Test #	Vehicle	Test Procedure	ES-2 Type	ATD Position	Impactor	Impactor Orienta-tion	Airbag
4389	1999 Volvo S80	Oblique Pole	STD	201 Seating Position	10″ pole	75°	CURTAIN, THORAX
4378	2000 Saab 9-5	Oblique Pole	STD	201 Seating Position	10″ pole	75°	COMBO
4471	2002 Ford Explorer	Oblique Pole	re	201 Seating Position	10″ pole	75°	CURTAIN

Table X-3.1.8. Oblique Pole Impact Configuration for ES-2 & Restraint System Repeatability

Test #	Vehicle	Test Procedure	ES-2 Type	ATD Position	Impactor	Impactor Orienta-tion	Airbag
4285	1999 Nissan Maxima	Oblique Pole	STD	201 Seating Position	10″ pole	75°	NONE
4365	1999 Nissan Maxima	Oblique Pole	STD	201 Seating Position	10″ pole	75°	NONE
4423	1999 Nissan Maxima	Oblique Pole	re	201 Seating Position	10″ pole	75°	NONE

Table X-3.1.9. Oblique Pole Impact Configuration for ES-2 Seating Procedure

Test #	Vehicle	Test Procedure	ES-2 Type	ATD Position	Impactor	Impactor Orientation	Airbag
4498	1999 Volvo S80	Oblique Pole	re	214 Seating Position	10″ pole	75°	CURTAIN, THORAX
4497	2000 Saab 9-5	Oblique Pole	re	214 Seating Position	10″ pole	75°	COMBO
4859	2004 Honda Accord	Oblique Pole	re	214 Seating Position	10″ pole	75°	CURTAIN, THORAX
4860	2004 Toyota Camry	Oblique Pole	re	214 Seating Position	10″ pole	75°	CURTAIN, THORAX

<u>Test Configurations</u>:

The test configuration for the FMVSS 214 speed/angle is fully described in 49 CFR Section 571.214, "Side Impact Protection"[3]. The impactor, whether an MDB or F150 pickup, is propelled at a 27 degree crab angle sideways into the stationary target vehicle at an impact speed of 54 km/h (33.5 mph) at a 90-degree contact angle. This test simulates a 90-degree intersection impact of a striking vehicle traveling 48 km/h (30 mph) into a target vehicle traveling 24 km/h (15 mph). The test configuration for Side NCAP is similar to FMVSS 214 but at the higher impact speed of 62 km/h (38.5 mph).

The test configuration for 201P is fully described in 49 CFR Section 571.201, "Head Impact Protection in Interior Impact" [34]. The test vehicle is propelled sideways at a speed of 29 km/h (18 mph) into a 10-inch diameter rigid pole at an angle of 90 degrees.

The test configuration for the Oblique Pole is more fully described in section X-3.5. The test vehicle is propelled sideways at a speed of 32 km/h (20 mph) into a 10-inch diameter rigid pole at an approach angle of 75 degrees.

Data Processing: Table X-3.2.1 provides a description of the ES-2 and ES-2re computed dummy responses that are presented in this chapter.

Table X-3.2.1 Dummy Reponses

	Data Processing	SAE J211 Filter Class
Head Resultant	head c.g. resultant acceleration	1000
HIC	$HIC36 = \max\left[\frac{1}{t_2 - t_1}\int_{t1}^{t2} a(t)dt\right]^{2.5} (t_2 - t_1)$ *where* $a(t)$ *is the resultant head acceleration* *and* $(t_2 - t_1) \leq 36\,m\sec$	1000
Upper Spine (g)	peak upper spine resultant acceleration	180
Lower Spine (g)	peak lower spine resultant acceleration	180
Max Rib (mm)	max of upper, middle, & lower peak rib deflections	180
Back plate X (N)	peak back plate X force	180
Back plate Y (N)	peak back plate Y force	600
Abdomen- Summed (N)	peak of sum of abdomen front, mid, and rear forces	600
Pubic Symphysis (N)	peak of pubic symphysis force	600

X-3.2 ES-2 Dummy Responses in the Higher Severity and Fleet Performance Crash Tests

In 2001 and 2002, the agency performed a series of 23 crash tests with ES-2 dummies in the crash configurations described in Tables X-3.1.1 through –4. The corresponding dummy responses are presented in Tables X.3.2.1 through – 3.2.5.b.

Table X-3.2.1.a. Cadillac Deville Tests, Driver, ES-2 Driver Body Loads

Test #	1999 Cadillac DeVille target vehicle	Max Rib (mm)	Back Plate X (N)	Back Plate Y (N)	Abdomen – Summed (N)	Pubic Symphysis (N)
3669	214 speed/angle (IIHS MDB)	-41.8	481.5	-331.9	4377.3*	-4732.3
3755	214 speed/angle (Ford F150)	-48.2	234.3	-197.8	1819.6	-2466.6
4086	Side NCAP (IIHS MDB)	-54.1	1390.1	-587	4953.3*	-5238.5
4094	Side NCAP (Ford F150)	-44.5	680.2	-215	2595.4	-4817.2

*High abdominal loads were caused by an intruding armrest as verified by crash test film review

Table X-3.2.1.b. Cadillac Deville Tests, ES-2 Driver Accelerations

Test #	1999 Cadillac DeVille target vehicle	Head Resultant (g)	HIC	Head Resultant Time (ms)	HIC t_1 (ms)	HIC t_2 (ms)	Lower Spine (g)	Upper Spine (g)
3669	214 speed/angle (IIHS MDB)	162.4	825	59	56.2	62	NVD*	NVD
3755	214 speed/angle (Ford F150)	61.2	376	81	66.2	94.3	38.8	33.9
4086	Side NCAP (IIHS MDB)	233	3986	46	43.9	50.7	91.5	102.1
4094	Side NCAP (Ford F150)	70.8	403	70	55.4	82.9	58.5	41.4

*NVD – No Valid Data

Table X-3.2.2.a. High Severity, FMVSS 214 Speed/Angle, Driver Body Loads – ES-2*

Test #	Vehicle	Max Rib (mm)	Back Plate X (N)	Back Plate Y (N)	Abdomen (summed) (N)	Pubic Symphysis (N)
3668	1999 Nissan Maxima (IIHS MDB)	-34.9	741.2	-408.2	2179	-4842.7
3679	1999 Geo Prizm (IIHS MDB)	-39	6684.4	8103.3	1672.1	-3432.8
3756	1999 Geo Prizm (Ford F150)	-42.1	2964.9	11533.2	1212.9	-2644
4482	1999 Geo Prizm (Ford F150) – (ES-2re)	-54.1	-4609.3	4226	1414	-2628

* all except Test # 4482

Table X-3.2.2.b. High Severity, FMVSS 214 Speed/Angle, Driver, Accelerations – ES-2*

Test #	Vehicle	Head Resultant (g)	HIC	Head Resultant Time (ms)	HIC t_1 (ms)	HIC t_1 (ms)	Lower Spine (g)	Upper Spine (g)
3668	1999 Nissan Maxima (IIHS MDB)	164.2	743	55	NVD	NVD	NVD	NVD
3679	1999 Geo Prizm (IIHS MDB)	110.1	543	35	32.7	50.7	NVD	NVD
3756	1999 Geo Prizm (Ford F150)	46.1	114	50	39.2	71.9	130.7	112.8
4482	1999 Geo Prizm (Ford F150) - (ES-2re)	87.6	314	49	46.4	61.2	109.9	95.1

*all except Test # 4482

Table 3.2.3.a. Side NCAP Tests, Driver, Body Loads - ES-2

Test #	Vehicle	Max Rib (mm)	Back Plate X (N)	Back Plate Y (N)	Abdomen – Summed (N)	Pubic Symphysis (N)
3799	2001 Focus	-46.4	434.4	1214.1	1785.2	-3560.6
3803	2002 Impala	-23.7	3353.5	4709.7	1171.1	-2078.3
4097	2003 Corolla	-39.2	578.4	-320.7	1594.6	-3638.9
3800	2002 Escape	-11.1	649.3	-414.5	1339.3	-3738.9
3819	2001 LeSabre	-55.8	1473.1	-1367	1323.8	-2420.1
3875	2002 Odyssey	-19.1	-904.7	704.1	1204.8	-2507.2
3899	2002 Tundra	-3.7	-2045.8	201.1	547.1	-1034.6

Table 3.2.3.b. Side NCAP Tests, Driver, Accelerations - ES-2

Test #	Vehicle	Head Resultant (g)	HIC	Head Resultant Time (ms)	HIC t_1 (ms)	HIC t_2 (ms)	Lower Spine (g)	Upper Spine (g)
3799	2001 Focus	53.2	299	54	43.6	79.6	73.5	82.8
3803	2002 Impala	79.1	307	49	42.9	53.2	58.4	45.4
4097	2003 Corolla	80.8	296	42	38.9	55.3	71.8	60.1
3800	2002 Escape	29	74	48	43.5	77.7	53.9	39.1
3819	2001 LeSabre	211.9	712	47	46	49.3	71.8	87.9
3875	2002 Odyssey	33.2	68	71	57.1	82.4	43.4	30.7
3899	2002 Tundra	52.3	74	54	50.4	73.7	20.8	32.3

Table 3.2.3.c. Side NCAP Tests, Rear Passenger, Body Loads - ES-2

Test #	Vehicle	Max Rib (mm)	Back Plate X (N)	Back Plate Y (N)	Abdomen – Summed (N)	Pubic Symphysis (N)
3799	2001 Focus	-17.5	-802.7	-491.7	1187.8	-3678
3803	2002 Impala	8	954.8	-621.9	4565.6	-4108.3
3800	2002 Escape	-18.4	-117.1	-365	1085.1	-2636.4
3819	2001 LeSabre	18.7	883.1	609	3109.7	-4038.2

Table 3.2.3.d. Side NCAP Tests, Rear Passenger, and Accelerations - ES-2

Test #	Vehicle	Head Resultant (g)	HIC	Head Resultant Time (ms)	HIC t_1 (ms)	HIC t_2 (ms)	Lower Spine (g)	Upper Spine (g)
3799	2001 Focus	81.1	188	43	40.3	46.4	63.4	46.9
3803	2002 Impala	72.3	284	53	47.8	60.4	60.9	48.8
3800	2002 Escape	84.1	370	61	57.2	67.4	44.1	44
3819	2001 LeSabre	58.9	220	54	46.4	62.9	68.2	46.3

Table X-3.2.4.a. FMVSS 201P Pole Tests- Dummy Evaluation, Driver, Body Loads - ES-2

Test #	Vehicle	Max Rib (mm)	Back Plate X (N)	Back Plate Y (N)	Abdomen – Summed (N)	Pubic Symphysis (N)
3708	2001 Saturn	-44.8	723.4	1773.7	1022.4	-1558.8
3740	2001 Saturn (curtain)	-46	501.8	2047.3	1083.7	-1917.2
3703	1999 Maxima	-45.1	243.3	-294.2	1757.7	-1930.1
3707	1999 Maxima (combo)	-33.3	110.1	278.9	1449.8	-2079.9

Table X-3.2.4.b. FMVSS 201P Pole Tests- Dummy Evaluation, Driver Accelerations - ES-2

Test #	Vehicle	Head Resultant (g)	HIC	Head Resultant Time (ms)	HIC t_1 (ms)	HIC t_2 (ms)	Lower Spine (g)	Upper Spine (g)
3708	2001 Saturn	846.1	9004	60	59.1	59.9	58.3	44.9
3740	2001 Saturn (curtain)	88.7	435	129	49.6	67.9	68	47.1
3703	1999 Maxima	532.1	4728	59	58.5	59.5	55.5	52.4
3707	1999 Maxima (combo)	36.3	130	58	45.7	76.5	45.7	36.8

Table X-3.2.5.a. FMVSS 201P Pole Tests- Fleet Performance, Driver, Body Loads - ES-2

Test #	Vehicle	Max Rib (mm)	Back Plate X (N)	Back Plate Y (N)	Abdomen – Summed (N)	Pubic Symphysis (N)
3802	1999 Mercury Cougar	-41.5	1266.8	664.7	858.7	-2214.4
3818	1999 Saab 9-5	-37.8	534.2	-225.3	848.8	-1733.1
3820	1999 Volvo S80	-41.5	690.7	324.4	1217.1	-1166
3845	1999 Ford Windstar	-31.4	-1097.7	193.9	2352.4	-1382.2
3898	2002 Ford Explorer	-45.9	308.1	-541.7	2073.5	-1262.1

Table 3.2.5.b. FMVSS 201P Pole Tests- Fleet Performance, Driver, Accelerations - ES-2

Test #	Vehicle	Head Resultant (g)	HIC	Head Resultant Time (ms)	HIC t_1 (ms)	HIC t_2 (ms)	Lower Spine (g)	Upper Spine (g)
3802	1999 Mercury Cougar	59.4	313	56	45.9	67.6	56.6	51.4
3818	1999 Saab 9-5	35	114	58	42.8	69.9	40.2	38.4
3820	1999 Volvo S80	53.3	244	60	46.3	71.1	36.7	27.2
3845	1999 Ford Windstar	43.8	164	59	48.5	72.2	53.3	42.8
3898	2002 Ford Explorer	49.1	208	58	50.5	73.1	65.5	53.4

X-3.2.3. "Flat Top" in ES-2 rib deflection response

For the 23 crash tests with the ES-2 described in Tables X-3.1.1 through -3.1.4, rib deflection flat top response due to binding in the rib module was not an issue. The 23 tests correspond to the measurement of 102 rib deflections for both front and rear seated dummies. There were only three instances of "flat top" observed in the rib deflections:

- Two instances of flat topping are attributed to load sharing with the shoulder in one case (IIHS MDB/Prizm- test # 3679) and with the back plate in the other case (pole/Cougar driver- test # 3802) as shown in Figures X-3.2.2 through -3.2.5.
- One instance of flat topping is attributed to the response reaching maximum deflection range (IIHS MDB/Cadillac driver at NCAP speed- test # 4086) as shown in Figure X-3.2.6.

Earlier tests, both at NHTSA and EU, had identified a number of causes of rib deflection flat-topping [2, 27]: Unacceptable flat top signatures are due to either rib(s) binding, shoulder binding, or load sharing with the back plate. Acceptable flat tops would be caused by load sharing with other body regions, attenuation of input load, and reaching maximum deflection range. It is worth noting that in addition to the crash test evaluation, no "flat top" behavior was observed in oblique pendulum and rib drop tests conducted by NHTSA.

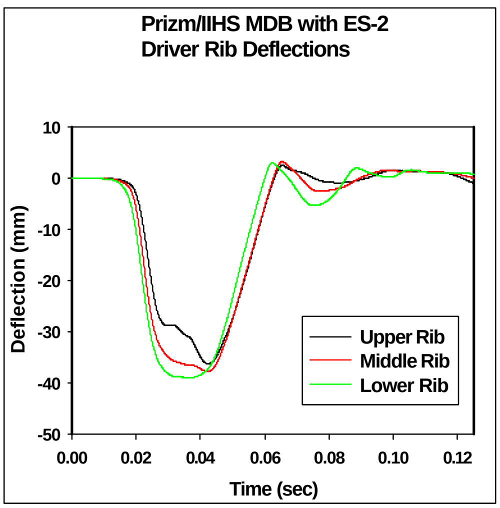


Figure X-3.2.2. Flat top in lower rib

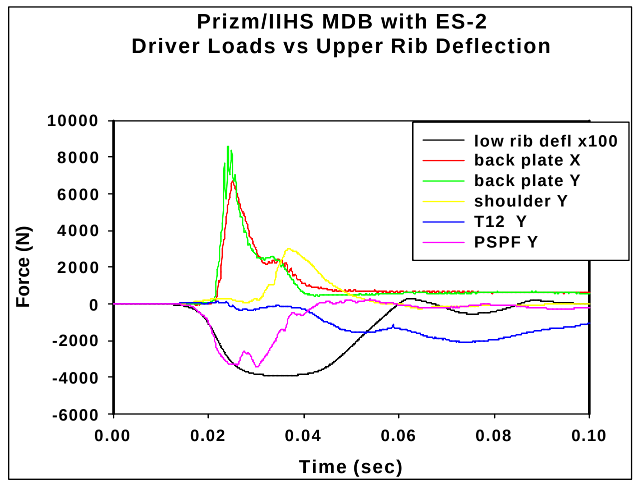


Figure X-3.2.3. Load sharing with the shoulder

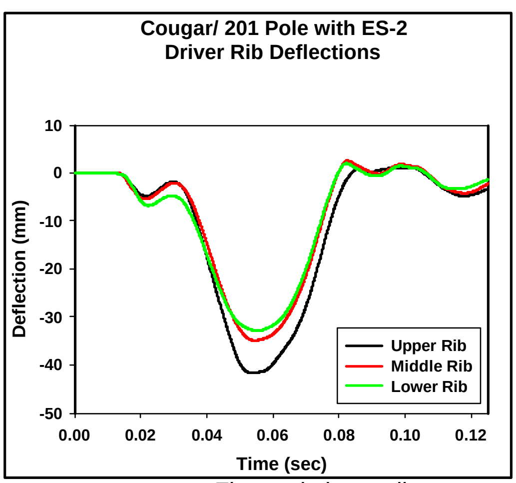


Figure X-3.2.4. Flat top in lower rib

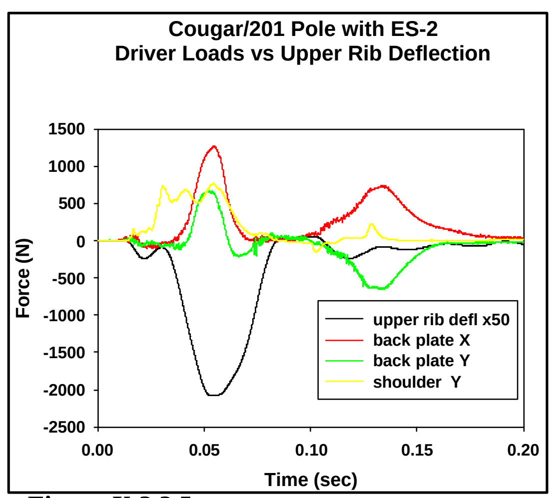


Figure X-3.2.5. Load sharing with back plate

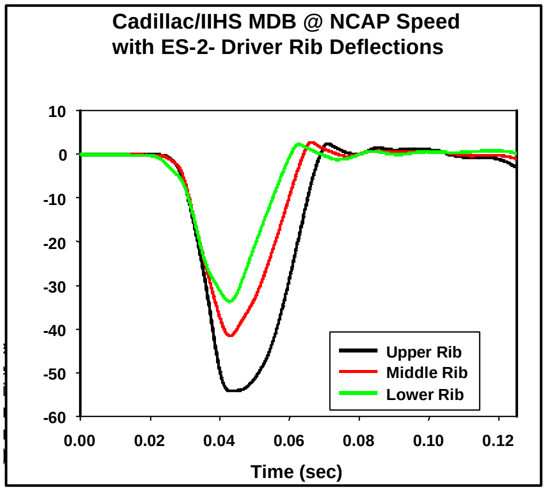


Figure X-3.2.6 Upper rib at maximum range

X-3.2.4. ES-2 back plate to seatback interaction

In the 23 tests performed, large back plate loads were recorded for two out of the seventeen vehicle models tested: the 1999 Geo Prizm (#3679 and #3756) and the 2002 Impala (#3803) . Back plate loads and corresponding momentum contribution were low for the remaining fifteen vehicle models. The peak torso back plate loads and timing are presented in Tables X-3.2.6 and –3.2.7 for the 23 tests. For the Geo Prizm and Impala models, large positive lateral back plate loads, early in time relative to the lower spine loads, were observed (Figures X-3.2.8-3.2.10). The data demonstrate substantial localized loads to the dummy through the back plate. This implies the dummy back plate was "grabbed" by the approaching seat back structure (Figure X-3.2.7). The back plate is being pushed laterally inboard away from the intruding structure. The concern is that "grabbing" of the back plate by the seat frame off-loads the thorax and thus limits rib deflections.

The rated capacity of the torso back plate load cell is Fx=3000 N, Fy=3000 N, My=160 Nm, and Mz=160 Nm. As such, the lateral loads of 8 kN and 11 kN, and moments of 393 and 246 Nm, respectively, measured in the Geo Prizm crash tests were extremely high and far over the capacity of the load cell. To confirm the validity of the recorded values, the load cell was carefully inspected and recalibrated successfully in overload conditions by FTSS at load levels similar to those recorded in the Geo Prizm tests.

Table X-3.2.6. ES-2 Back Plate Loads –High Severity MDB & Vehicle-to-Vehicle Crashes

ES-2 Torso Back Plate Loads									
	Driver					Rear Occupant			
	Fy(N)	Time(ms)	Fx(N)	My(N-m)	Mz(N-m)	Fy(N)	Time(ms)	Fx(N)	My(N-m)
2002 Side NCAP Fleet Performance ES-2 Tests									
Focus	1214	39	434	20	17	-492	44	803	-39
Corolla						CRS child dummies in rear			
Impala (combo)	4710	33	3354	78	149	-622	77	955	-41
LeSabre	-1367	103	1473	-58	-102	609	46	883	-9
Escape	-415	53	649	-19	28	-365	56	-117	7
Odyssey (thorax)	704	40	-905	-40	33	CRS child dummies in rear			
Tundra	201	146	-2046	-130	83				
FMVSS 214 MDB Upgrade/High Severity Tests									
Prizm/IIHS MDB	8103	24	6684	393	246	-565	90	1931	39
Prizm/F150	11533	33	2965	-67	155	-520	98	1088	-25
Deville/IIHS MDB	-332	43	482	-25	20	-484	60	1143	-12
Deville/F150	-198	43	234	-13	18	-363	61	364	-12
NCAP Deville/IIHS MDB	-587	111	1390	-28	-41	-821	51	1323	-14
NCAP Deville/F150	-215	61	680	-16	32	-520	53	611	-9
Maxima/IIHS MDB	-408	37	741	-23	26.7	-161	79	554	-18

Table X-3.2.7 ES-2 Back Plate Loads- 201P Pole tests

ES-2 Torso Back Plate Loads in Pole Tests					
	Driver				
	Fy(N)	Time(ms)	Fx(N)	My(N-m)	Mz(N-m)
Saturn	1774	52	723	21	31
Saturn (curtain)	2047	49	502	-9	17
Maxima	-294	42	243	-14	17
Maxima (combo)	279	49	110	17	19
Cougar (combo)	665	51	127	-37	59
Saab (combo)	-225	63	534	13	22
Volvo (thorax/curtain)	324	43	691	-14	28
Windstar (combo)	194	58	-1098	35	24
Explorer (curtain)	-542	55	308	-5	11

Figure X-3.2.7 ES-2 (no torso jacket) in Prizm seat back frame exposed

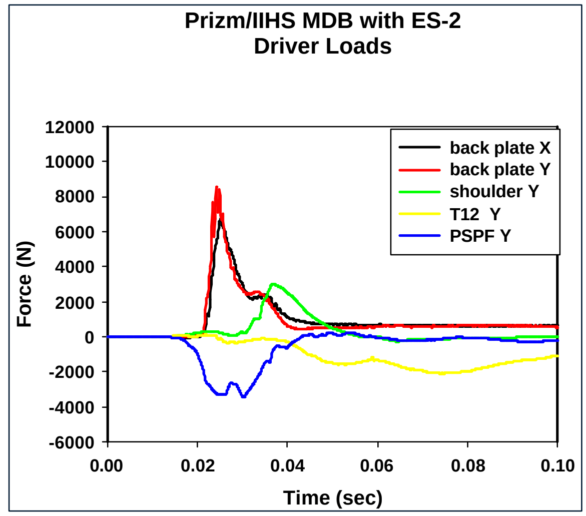
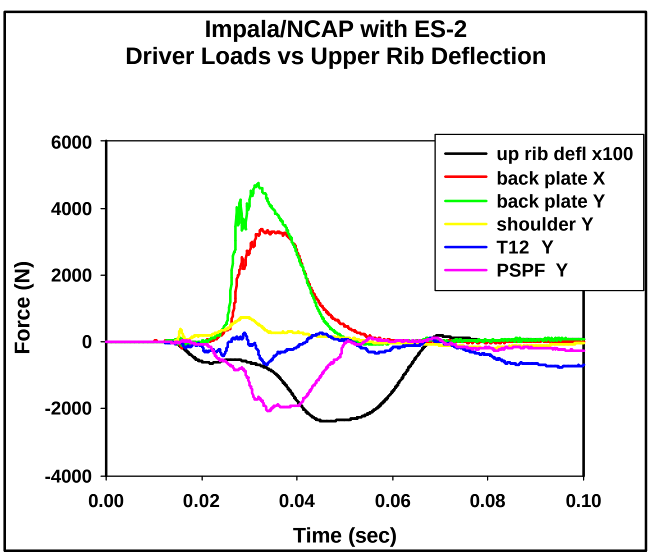


Figure X-3.2.8 Prizm/IIHS ES-2 driver loads



FigureX-3.2.9 Impala Side NCAP ES-2 Driver

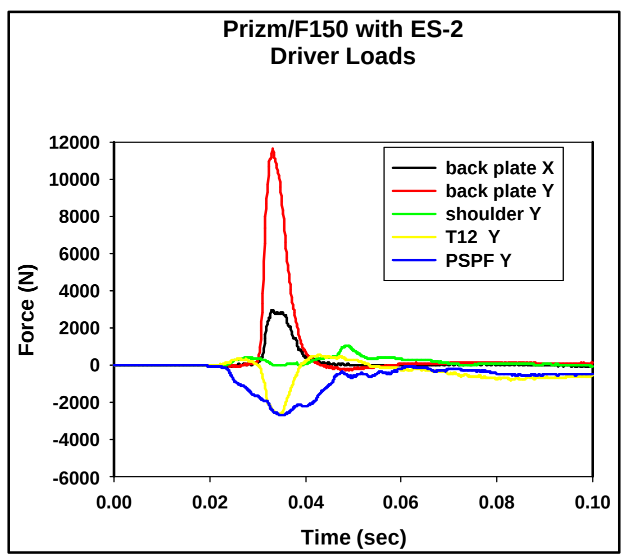


Figure X-3.2.10 Prizm/F150 ES-2 Driver

X-3.3. ES-2 re Development

In June of 2002, based on NHTSA crash test results, FTSS developed a hardware retro fix [30], a rib extension design (re) that encloses the gap of the ES-2 rib cage between the ribs and the back plate. The mechanism is designed to eliminate the potential “grabbing” effects between the ES-2 back plate and the vehicle seat back. The ES-2re rib extension modification includes redesigned replacement ribs that extend from the lateral portion of the non-struck side of the thorax, around the sternum and struck-side, and end at the posterior aspect of the spine, Figures X-3.3.1 and –3.32**.** The extended ribs provide a continuous loading surface that nearly encircles the thorax and enclose the posterior gap of the ES-2re ribcage. A new back plate designed, with needle bearings and a Teflon cover retain the ends of the extended ribs. The new back plate is made of aluminum for providing enough strength to retain the bearing shaft.

FTSS provided evidence to have verified the ES-2re design through rib certification tests, whole dummy pendulum tests and finite element modeling [31,32, 33]. The data indicate that the rib extension mechanism has minimal effect on the certification response of the dummy.

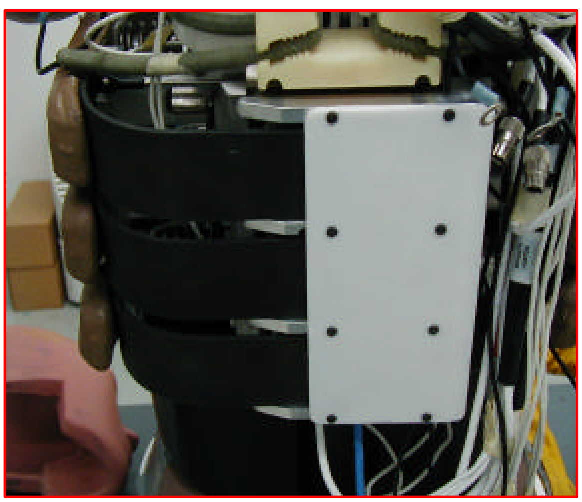


Figure X-3.3.1- ES-2re with production rib extensions and modified back plate

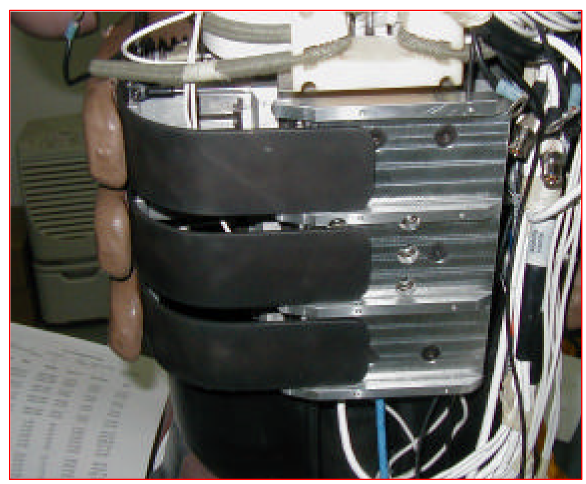


Figure X-3.3.2. - ES-2re with production rib extensions and modified back plate (cover removed)

X-3.3.1 Comparison of ES-2re and ES-2 barrier to vehicle crash tests results

Crash Tests

Upon completion of the ES-2re development comparison tests with the ES-2 were initiated in a matrix as shown in Table X-3.3.1. Initial comparison was performed in the Side NCAP test environment with the Impala vehicle. The peak lateral back plate load of the ES-2re was reduced from approximately 4700 N to -540 N (Figure X-3.3.1). Interaction of the dummy in the anterior-posterior direction with the Impala seat back remained basically unchanged based on a comparison of the longitudinal back plate loads of the ES-2 and ES-2re (Figure X-3.3.2).

Table X-3.3.1. ES-2 vs. ES-2 re Evaluation

Vehicle	Configuration
2001 Focus	Side NCAP
2003 Corolla	Side NCAP
2002 Impala	Side NCAP
1999 Prizm	F150 striking vehicle (FMVSS 214 speed/angle)

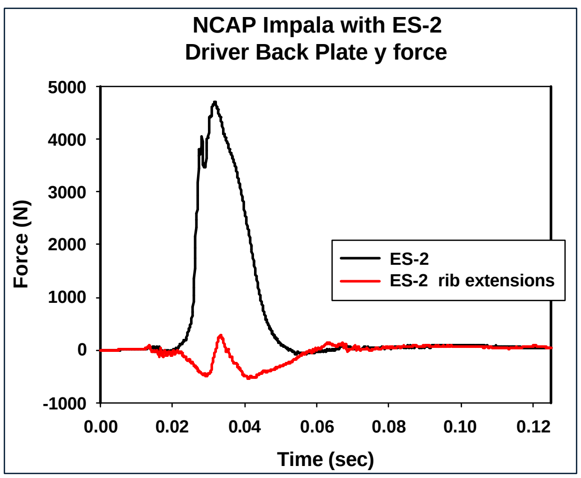


Figure X-3.3.3

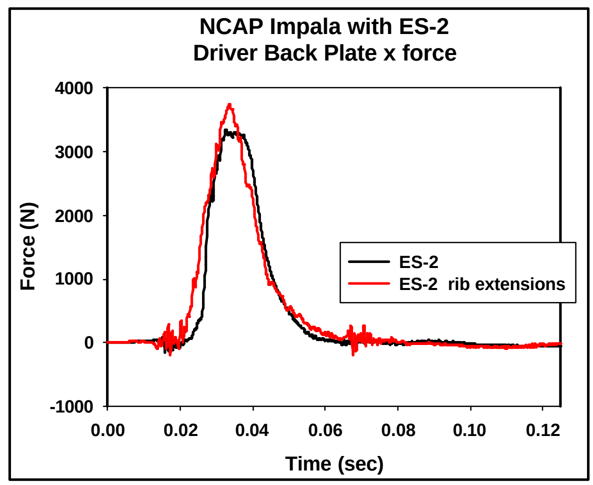


Figure X-3.3.4

The other measured dummy responses show relatively small increases in the peak levels for the ES-2re (Figure X-3.3.5). This response is expected since the localized back plate load path has been mostly eliminated and the energy was transferred to the dummy elsewhere. The momentum transfer that was passed through the back plate is now being directed mainly through the ribs and partly through the shoulder. As expected, the rib deflections have increased substantially in the ES-2re over the ES-2 for the Impala test (Figures X-3.3.6 through 3.3.8). Rib displacements start to diverge at about 18 ms, likely due to the earlier contact of the rib extensions with the seat side bolster and seat mounted airbag of the Impala.

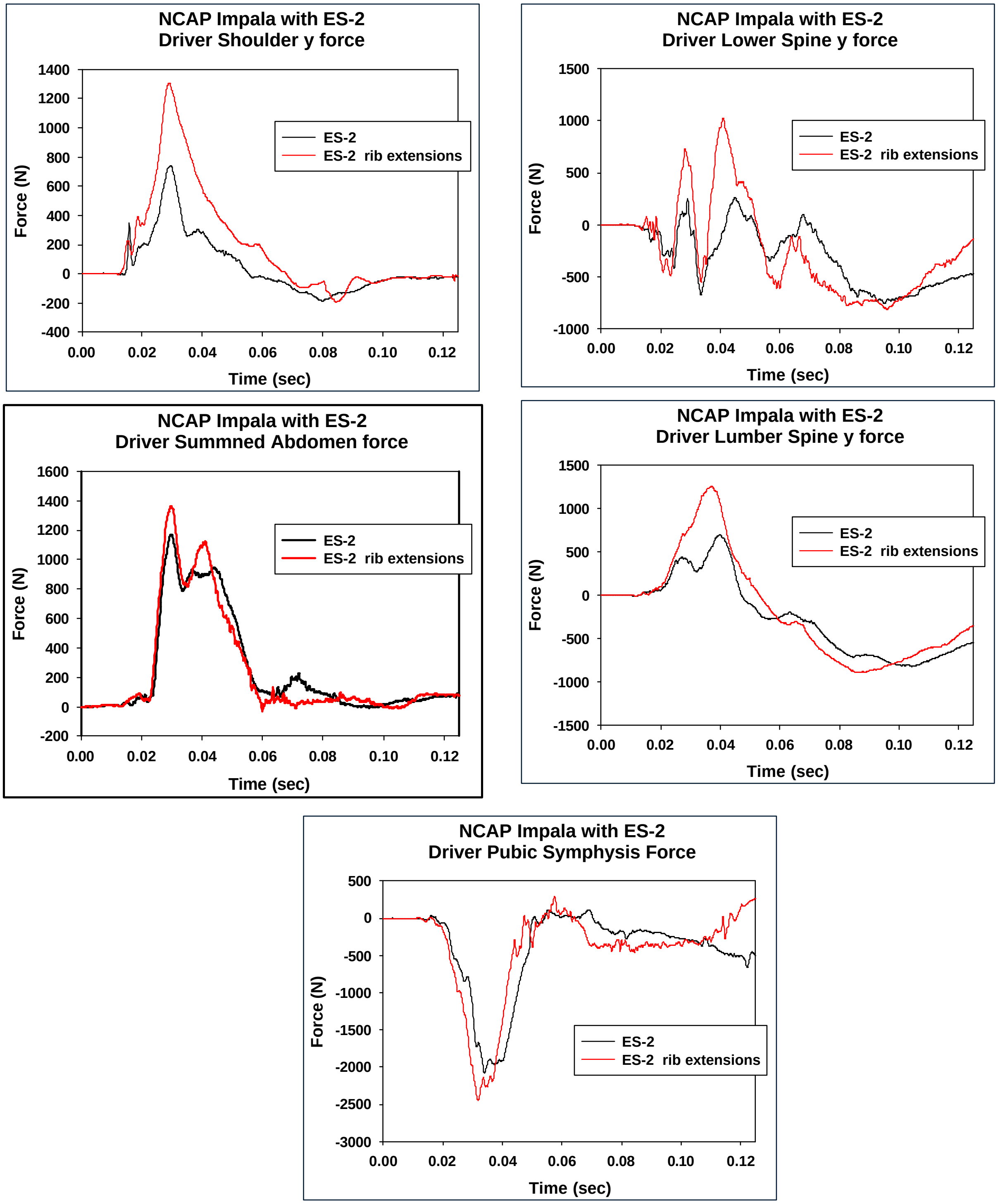
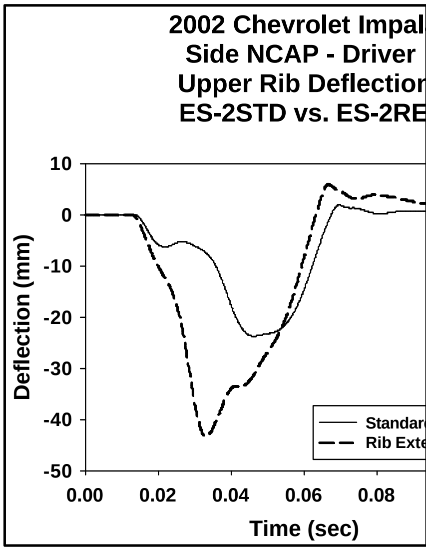
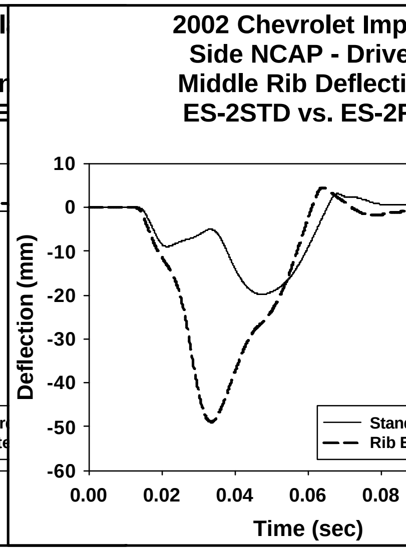


Figure X-3.3.5 Side NCAP Impala, Driver ES-2 vs. ES-2re body





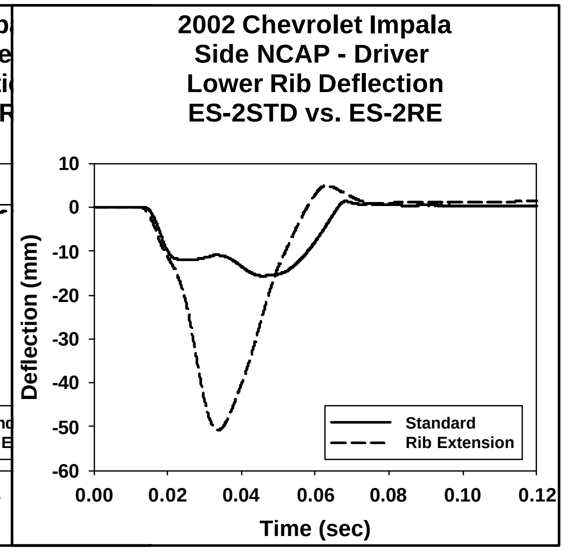


Figure X-3.3.6 **Figure X-3.3.7** **Figure X-3.3.8**

Similar results were seen when the F150- to-Geo Prizm (test # 3756 - FMVSS 214 speed/angle) crash test was repeated with the ES-2re (test #4482). The comparison data for the Prizm tests are presented in Tables X-3.2.2.a and –3.2.2.b. Although the peak lateral back plate load was reduced from 11.5 kN to 4.2 kN in ES-2re, the load was still large. This test presented a severe loading environment resulting in bottoming out of the driver middle and lower ribs. The load from the intruding seat structure was likely transferred through the rib extensions to the back plate. The longitudinal back plate load is negative for the ES-2re indicating that the back plate is being pushed backward into the seat back.

Two ES-2 vs. ES-2re comparison tests were also conducted in 2001 Focus (tests #3799/4456) and 2003 Corolla (#4097/4455) in the US side NCAP configuration. The Focus ES-2 test data indicated a localized but small load through the dummy back plate while the Corolla ES-2 test data had no indication of such an interaction. In the Focus test with the ES-2, the peak lateral back plate load was 1.2 kN. In the Corolla test with the ES-2, the peak lateral back plate load was –0.3 kN. A comparison of the peak dummy responses is presented in Tables X-3.3.2.a through -.d. Overlay plots comparing ES-2re and ES-2 driver back plate, abdomen and pubic loads for the Focus and Corolla are displayed in Figures X-3.3.9 through -12. The HIC, peak rib deflections, the abdominal and the pubic loads were comparable for the ES-2re and ES-2 in the Focus and Corolla given test-to test variability (in case of the Corolla tests, there was a 26 mm difference in MDB lateral impact point location). In particular, the abdominal and pubic loads time histories demonstrate very good repeatability.

Two additional FMVSS 214 tests were conducted to assess the performance of the ES-2re with production version of the retro fix upgrade in 2001 Focus (#4547) and 2002 Impala (#4551) models . Some of the peak dummy responses are presented in Tables X-3.3.3.a through –d. The dummy's back plate low lateral load measurements in both vehicles indicate absence of grabbing of the seat back structure.

Table X-3.3.2.a.: Side NCAP, ES2 vs. ES-2re, Driver, Body Loads

Test #	Vehicle	Max Rib (mm)	Back Plate X (N)	Back Plate Y (N)	Abdomen – Summed (N)	Pubic Symphysis (N)
3799	2001 Focus	-46.4	434.4	1214.1	1785.2	-3560.6
4456	2001 Focus (re)	-47.6	1416.2	-797.2	1857.9	-3628.7
3803	2002 Impala	-23.7	3353.5	4709.7	1171.1	-2078.3
4380	2002 Impala (re)	-50.8	3744.2	-538.9	1364.3	-2442.2
4097	2003 Corolla*	-39.2	578.4	-320.7	1594.6	-3638.9
4455	2003 Corolla (re)**	-44.3	1478.5	-549.4	1986.4	-3373.9

* Impact point 14 mm rear while ** impact point is 12 mm forward; 26mm difference in impact point location between two tests.

Table X-3.3.2.b.: Side NCAP, ES-2 vs. ES-2re, Driver, Accelerations

Test #	Vehicle	Head Resultant (g)	HIC	Head Resultant Time (ms)	HIC t_1 (ms)	HIC t_2 (ms)	Lower Spine (g)	Upper Spine (g)
3799	2001 Focus	53.2	299	54	43.6	79.6	73.5	82.8
4456	2001 Focus (re)	53.1	272	49	42.7	78.7	81.5	63.4
3803	2002 Impala	79.1	307	49	42.9	53.2	58.4	45.4
4380	2002 Impala (re)	44.1	137.9	45.8	41.9	66.4	67	52.4
4097	2003 Corolla*	80.8	296	42	38.9	55.3	71.8	60.1
4455	2003 Corolla (re)**	87	349	41	37.9	51.3	70.8	64.5

* Impact point 14 mm rear while ** impact point is 12 mm forward; 26mm difference in impact point location between two tests.

Table X-3.3.2.c.: Side NCAP, ES-2 vs. ES-2re, Rear Passenger, Body Loads

Test #	Vehicle	Max Rib (mm)	Back Plate X (N)	Back Plate Y (N)	Abdomen – Summed (N)	Pubic Symphysis (N)
3799	2001 Focus	-17.5	-802.7	-491.7	1187.8	-3678
4456	2001 Focus (re)	-24.5	1032.9	-653.7	2036	-3724.5
3803	2002 Impala	8	954.8	-621.9	4565.6	-4108.3
4380	2002 Impala (re)	-8.9	2136.3	-987.8	4433.6	-5125.1
4455	2003 Corolla (re)	-28.6	578	-737.8	1833.9	-3130

Table X-3.3.2.d.: Side NCAP, ES-2 vs. ES-2re, Rear Passenger, Accelerations

Test #	Vehicle	Head Resultant (g)	HIC	Head Resultant Time (ms)	HIC t_1 (ms)	HIC t_2 (ms)	Lower Spine (g)	Upper Spine (g)
3799	2001 Focus	81.1	188	43	40.3	46.4	63.4	46.9
4456	2001 Focus (re)	72	236	41	37.3	58.8	68.5	53.5
3803	2002 Impala	72.3	284	53	47.8	60.4	60.9	48.8
4380	2002 Impala (re)	61.9	213.15	46.9	42.5	64.2	66	55.4
4455	2003 Corolla (re)	85.7	369	47	42.2	56.2	71.7	45.1

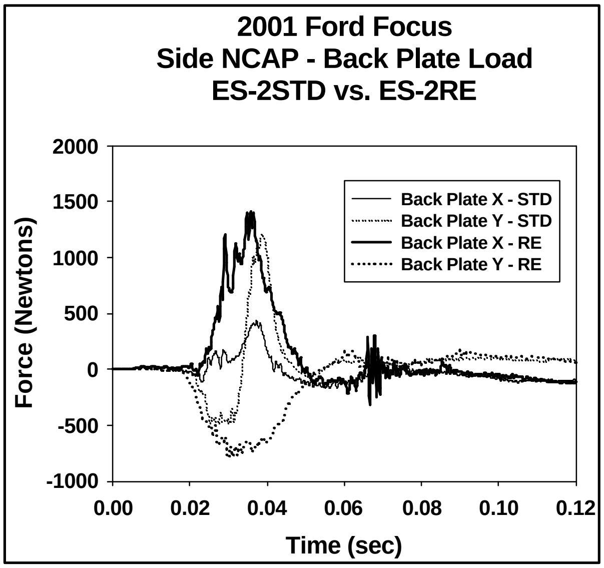


Figure X-3.3.9

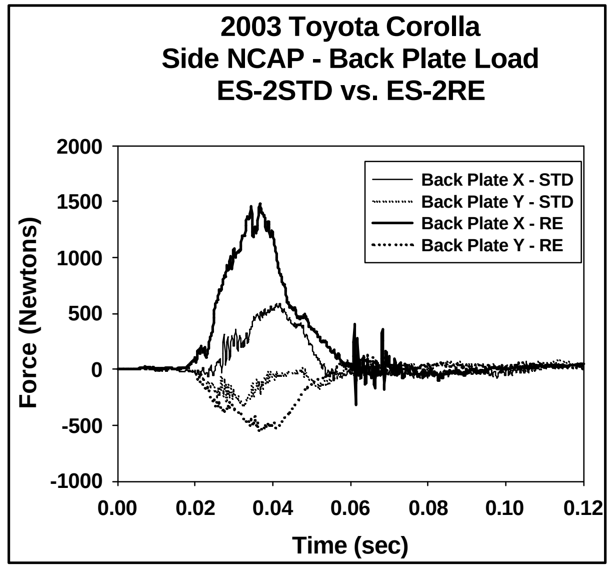


Figure X-3.3.10

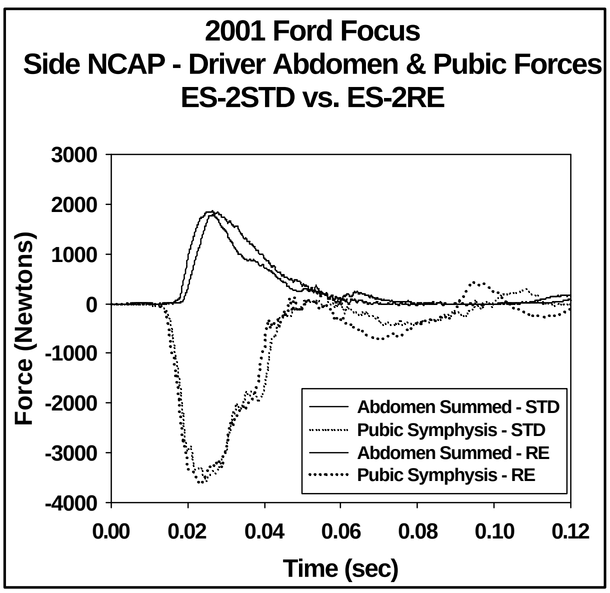


Figure X-3.3.11

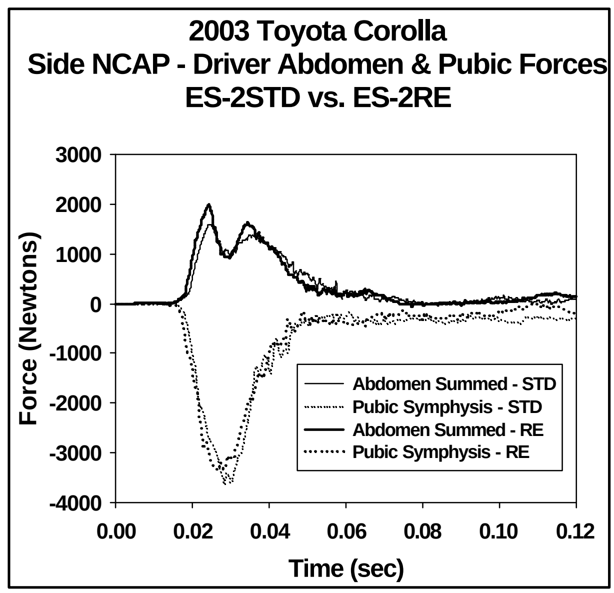


Figure X-3.3.12

Table X-3.3.3.a. FMVSS 214, Driver, Body Loads – ES-2re

Test #	Vehicle	Max Rib (mm)	Back Plate X (N)	Back Plate Y (N)	Abdomen – Summed (N)	Pubic Symphysis (N)
4547	2001 Focus (re)	-36.3	596.7	-630.9	1648.2	-2832.9
4551	2002 Impala (re)	-45.7	2592.7	-458.6	1225.2	-1788.7
4862	2004 Accord (re)	-36.9	1922.6	-519.0	556.7	-1982.7

Table X-3.3.3.b. FMVSS 214, Driver, Accelerations – ES-2re

Test #	Vehicle	Head Resultant (g)	HIC	Head Resultant Time (ms)	HIC t_1 (ms)	HIC t_2 (ms)	Lower Spine (g)	Upper Spine (g)
4547	2001 Focus (re)	36.1	136.7	57.8	46	82	59.7	55.3
4551	2002 Impala (re)	29.9	68.9	56.2	45.6	81.6	49.3	34.6
4862	2004 Accord (re)	35.4	109	53.8	34.6	64.2	37.5	44.9

Table X-3.3.3.c. FMVSS 214, Rear Passenger, Body Loads – ES-2re

Test #	Vehicle	Max Rib (mm)	Back Plate X (N)	Back Plate Y (N)	Abdomen – Summed (N)	Pubic Symphysis (N)
4547	2001 Focus (re)	-19.9	805.4	-606.9	1121.1	-2758.6
4551	2002 Impala (re)	-12.4	431.9	-539.7	4408.8	-2784.3
4862	2004 Accord (re)	-22.7	264.5	-476.6	809.7	-2404.9

Table X-3.3.3.d. FMVSS 214, Rear Passenger, Accelerations - ES-2re

Test #	Vehicle	Head Resultant (g)	HIC	Head Resultant Time (ms)	HIC t_1 (ms)	HIC t_2 (ms)	Lower Spine (g)	Upper Spine (g)
4547	2001 Focus (re)	80	174.2	45.6	41.8	62.2	58.9	47.8
4551	2002 Impala (re)	59.6	186.5	55	49.3	62.4	58.3	52.2
4862	2004 Accord (re)	69.5	223	50.4	47.2	58.7	50.3	39.0

X-3.4. ES-2 Head Response in FMVSS 201P Pole Crash Tests

Matched pair FMVSS 201P full-scale pole crash tests were performed using the SIDH3 and ES-2 dummies. One objective was to study the ability of the ES-2 dummy to assess the head protection system in comparison to the SID/HIII in pole test crash tests.

The data in Table X-3.4.1 and Figures X-3.4.1 through –3.4.5 show that in the 201P test, the ES-2 and SID/HIII dummies produce similar head loading levels and timing and comparable HIC values in pole crash tests. Review of the test film indicated that, in 201P pole test configuration, both dummies had comparable head/neck/shoulder kinematics.

Table X-3.4.1 FMVSS 201P Pole Tests: ES-2 & SIDH3 Head Gs

	SIDH3		ES-2	
	HeadG y	Peak @ (ms)	HeadG y	Peak @ (ms)
Saturn	830	56	835	60
Saturn(curtain)	81	58	71	57
Maxima	730	60	502	59
Volvo(thorax/curtain)	51	67	50	60
Explorer(curtain)	39	58	45	58

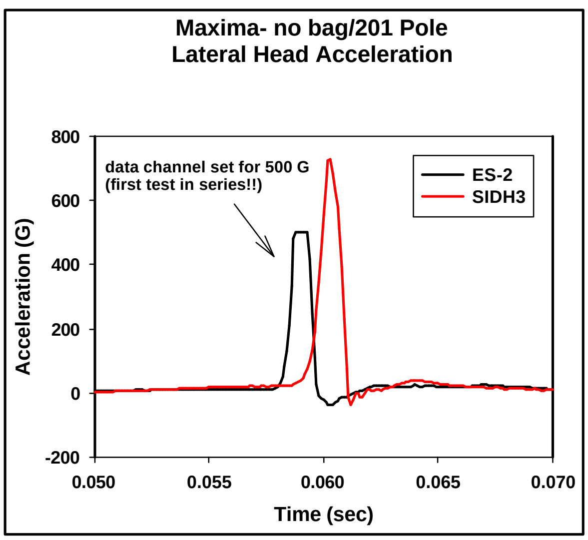


Figure X-3.4.1

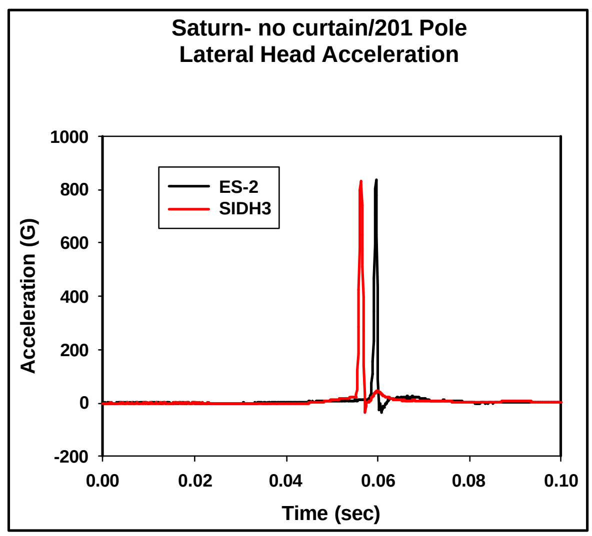


Figure X-3.4.2

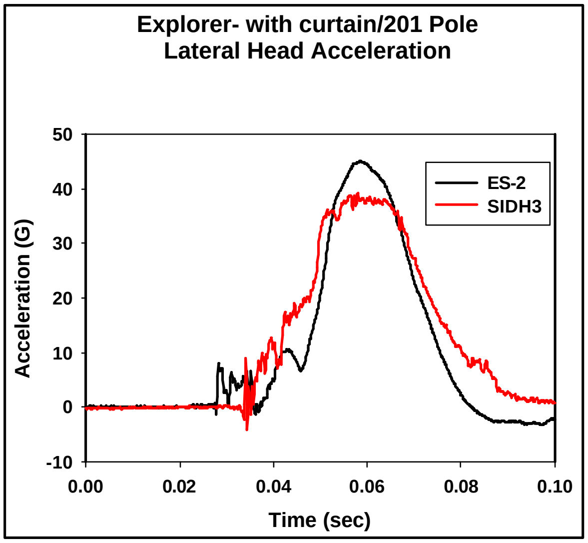


Figure X-3.4.3

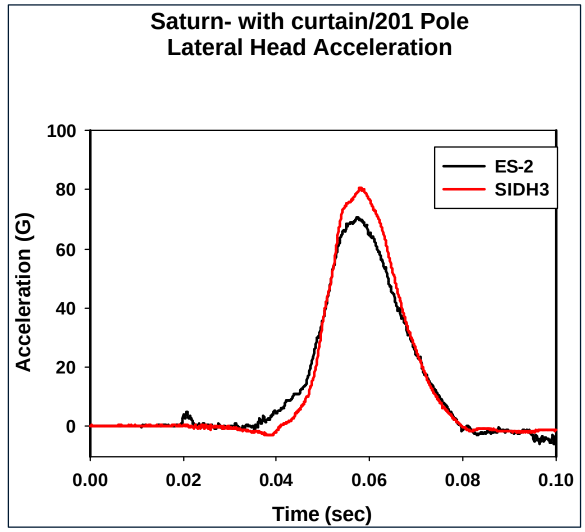


Figure X-3.4.4

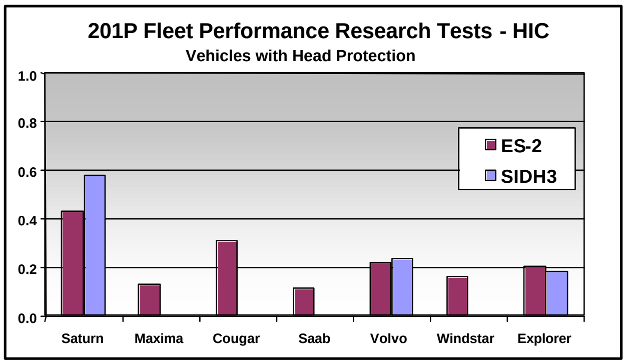


Figure -3.4.5

X-3.5 Oblique Pole ES-2 Crash Tests & ES-2 Repeatability

Research tests with the ES-2 were performed in an oblique pole impact configuration at 75º and 20 mph (32 km/h) (Figure X-3.5.1). One objective was to establish the feasibility of a pole test procedure that is representative of the side crash environment with narrow objects that loads both the chest and head regions of front seated occupants. Another objective was to assess the performance of the ES-2 dummy in this oblique pole impact configuration.

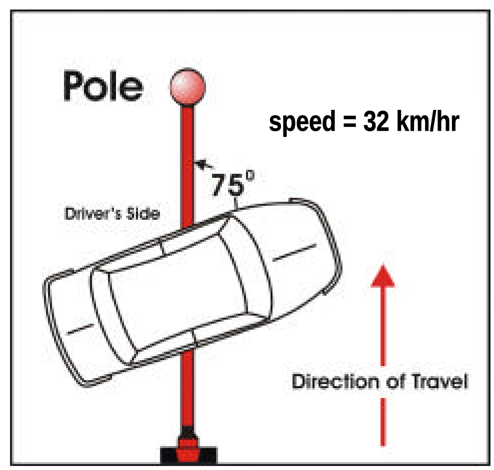


Figure X-3.5.1 Oblique pole test configuration

A total of fourteen oblique pole tests are presented in Tables X–3.1.6 through –3.1.9. Eight of these were performed with the ES-2 and six with ES-2re dummies. Peak dummy loads and acceleration responses are presented in corresponding Tables X-3.5.3.a. through –3.5.3.h. Tests with shaded highlights were conducted with the ES-2re.

In the fourteen tests oblique pole tests with both the ES-2 and ES-3re, rib deflection flat top response due to binding in the rib module was not an issue. Also, back plate lateral load measurements were low indicating absence of grabbing of the seat back structure.

Fifteen overlay plots of various body segment impact responses of ES-2 and ES-2re dummies in repeat oblique pole tests with a Nissan Maxima (Figure X-3.5.2) are presented at the end of this section. Test results indicate very good repeatability by the ES-2 and replication by the ES-2re of the ES-2 responses in this test configuration.

Table X-3.4.5.a: Oblique Pole, 201P Seating: Procedure Development, ES-2 Driver Body Loads

Test #		Max Rib (mm)	Back Plate X (N)	Back Plate Y (N)	Abdomen – Summed (N)	Pubic Symphysis (N)
4246	2001 Saturn	-49.7	244.7	-486.3	1622	-2783.6
4313	2001 Saturn (curtain)	-52.3	499.4	1344.3	1224	-2377.3
4285	1999 Maxima	-41.5	-146.9	-785	2150.6	-2548
4284	1999 Maxima (combo)	-35.7	288.2	-387.5	1196	-2368.4

Table X-3.4.5.b: Oblique Pole, 201P Seating: Procedure Development, ES-2 Driver Accelerations -

Test #	Vehicle	Head Resultant (g)	HIC	Head Resultant Time (ms)	HIC t_1 (ms)	HIC t_2 (ms)	Lower Spine (g)	Upper Spine (g)
4246	2001 Saturn	1215.7	15152	57	56.4	56.9	70.2	49.4
4313	2001 Saturn (curtain)	90.5	670	56	48.4	64.9	78.2	58.5
4285	1999 Maxima	964.1	11983	58	57.8	58.5	83.4	51.3
4284	1999 Maxima (combo)	625.1	5254	60	58.9	59.8	45.1	42.8

Table X-3.4.5.c: Oblique Pole, 201P Seating: ES-2 & Restraint System Performance, Driver Body Loads

Test #	Vehicle	Max Rib (mm)	Back Plate X (N)	Back Plate Y (N)	Abdomen – Summed (N)	Pubic Symphysis (N)
4389	1999 Volvo S80	-40.7	494.8	-253.6	1553.3	-1700.5
4378	2000 Saab 9-5	-49.9	286	-422.7	1381.5	-2672.6
4471	2000 Ford Explorer (re)	-43	-1069	-1129	2674.3	-2317.7

Table X-3.4.5.d: Oblique Pole, 201P Seating: ES-2 & Restraint System Performance, Driver Accelerations

Test #	Vehicle	Head Resultant (g)	HIC	Head Resultant Time (ms)	HIC t_1 (ms)	HIC t_2 (ms)	Lower Spine (g)	Upper Spine (g)
4389	1999 Volvo S80	72.6	465	61.4 ms	51.9	70.6	51.3	37.1
4378	2000 Saab 9-5	119.6	243	64.2 ms	50.8	66.2	58.3	57.8
4471	2000 Ford Explorer (re)	81.4	629	53 ms	46.2	64.4	98.4	79.9

Table X-3.4.5.e: Oblique Pole, 201P Seating: Dummy & Restraint System Repeatability, Driver Body Loads

Test #	Vehicle	Max Rib (mm)	Back Plate X (N)	Back Plate Y (N)	Abdomen – Summed (N)	Pubic Symphysis (N)
4285*	1999 Nissan Maxima	-41.5	-146.9	-785	2150.6	-2548
4365	1999 Nissan Maxima	-43.7	-192.7	-691	2014.3	-2495.3
4423	1999 Nissan Maxima (re)	-39.9	671	-1044	2249	-2465

Table X-3.4.5.f: Oblique Pole, 201P Seating: ES-2re & Restraint System Repeatability, Driver Accelerations

Test #	Vehicle	Head Resultant (g)	HIC	Head Resultant Time (ms)	HIC t_1 (ms)	HIC t_2 (ms)	Lower Spine (g)	Upper Spine (g)
4285*	1999 Nissan Maxima	964.1	11983	58	57.8	58.5	83.4	51.3
4365	1999 Nissan Maxima	1089.1	15591	55.9	55.5	56.2	84.6	50.3
4423	1999 Nissan Maxima (re)	1005.3	12144	57.8	57.4	58.1	89.4	50.4

Table X-3.4.5.g: Oblique Pole, 214 Seating: ES-2re Driver, Body Loads –

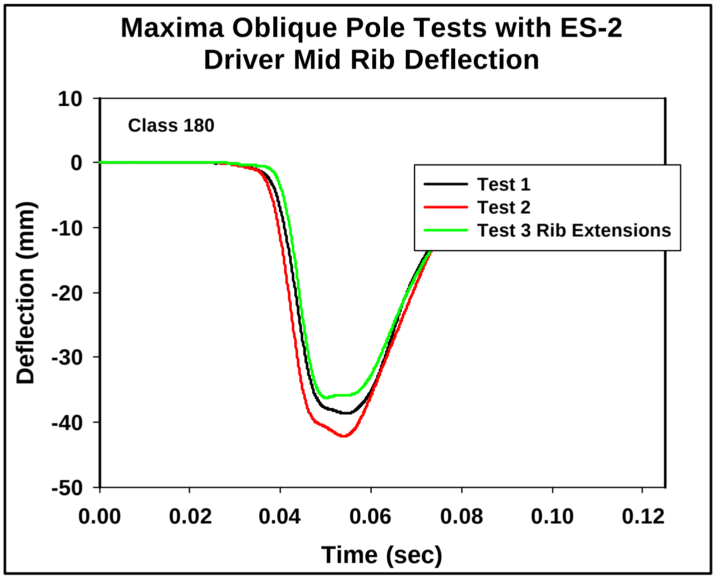
Test #	Vehicle	Max Rib (mm)	Back Plate X (N)	Back Plate Y (N)	Abdomen – Summed (N)	Pubic Symphysis (N)
4498	1999 Volvo S80 (re)	-48.6	833.4	-469.3	1546.6	-1127
4497	2000 Saab 9-5 (re)	-49.4	1072.3	-527.8	1365.6	-1733
4859	2004 Honda Accord (re)	-30.7	695.7	-570.6	1396.5	-2462.7
4860	2004 Toyota Camry (re)	-43.4	552.9	-605.5	1108.5	-1848.8

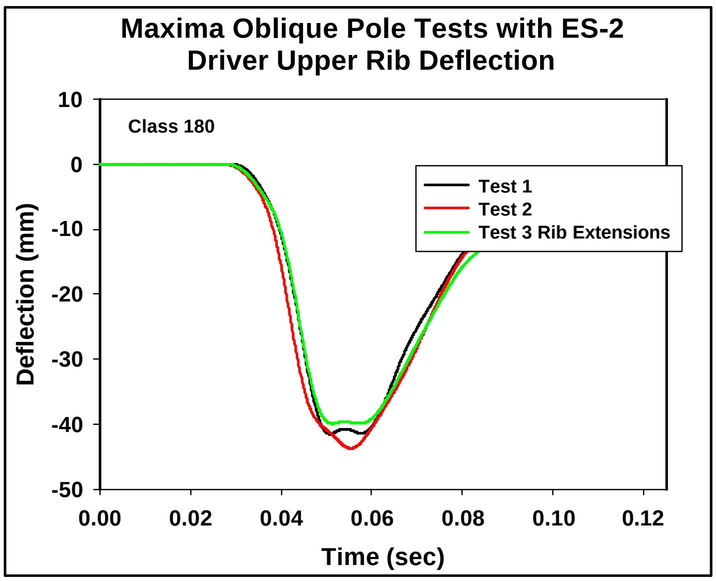
Table X-3.4.5.h: Oblique Pole, 214 Seating: ES-2re Driver, Accelerations,

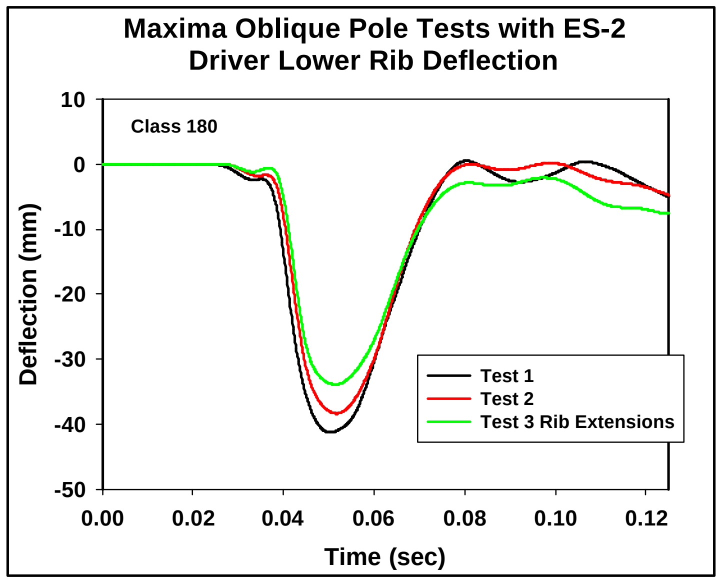
Test #	Vehicle	Head Resultant (g)	HIC	Head Resultant Time (ms)	HIC T1	HIC T2	Lower Spine (g)	Upper Spine (g)
4498	1999 Volvo S80 (re)	55	329	59.5	42.1	68.6	51.2	38.3
4497	2000 Saab 9-5 (re)	42.6	171	53.7	40.8	65	49	NVD*
4859	2004 Honda Accord (re)	61.8	446	52	40.9	65.2	51.7	49.0
4860	2004 Toyota Camry (re)	66.4	452	56.6	45.2	68.5	41.9	35.8

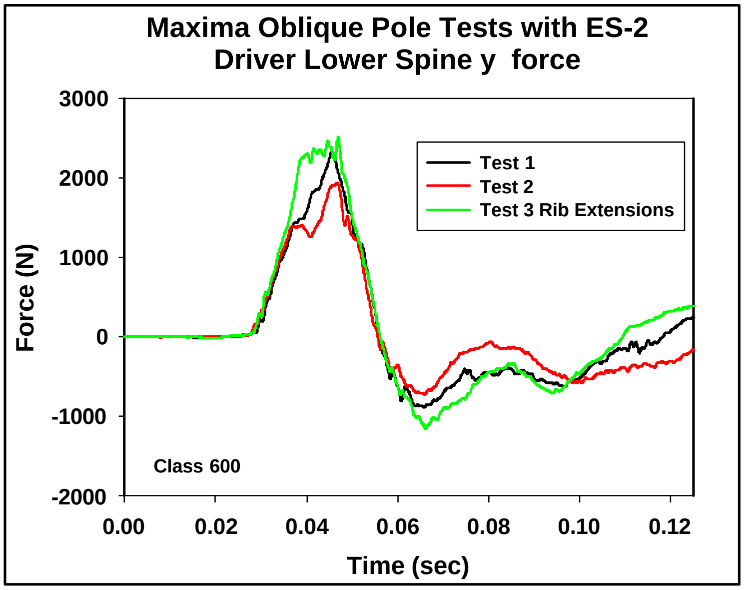
*NVD – No Valid Data

Figure X-3.5.2 (a set of 15 plots)








Maxima Oblique Pole Tests with ES-2
Driver Lower Spine y force
Test 1
Test 2
Test 3 Rib Extensions
Class 600
Force (N)
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-1000
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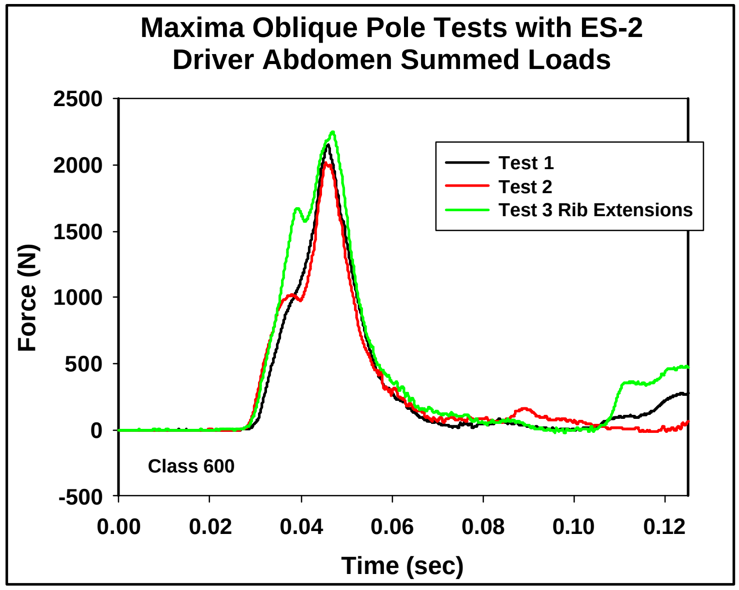
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Test 2
Test 3 Rib Extensions
Class 600
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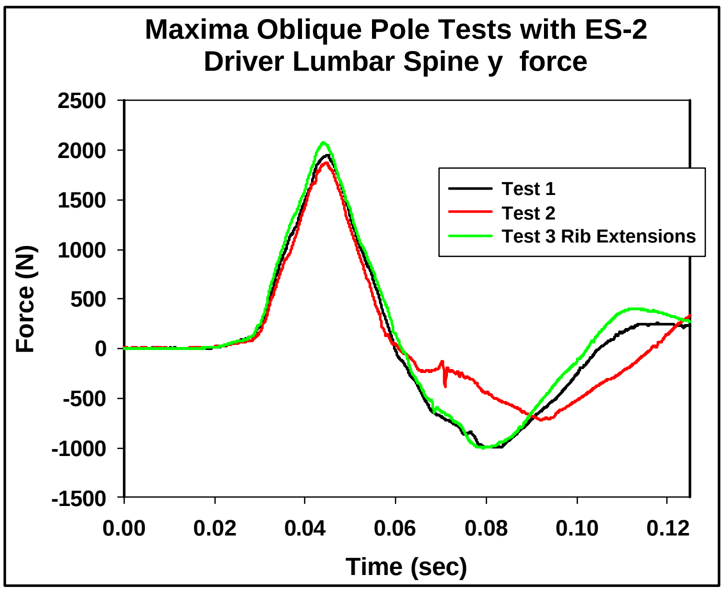
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Driver Lumbar Spine y force
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Test 2
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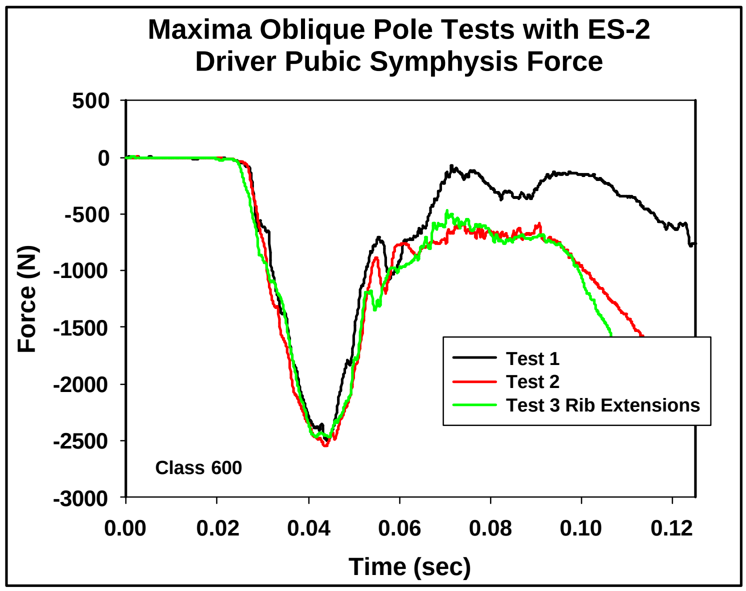
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Test 3 Rib Extensions
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Force (N)
Time (sec)
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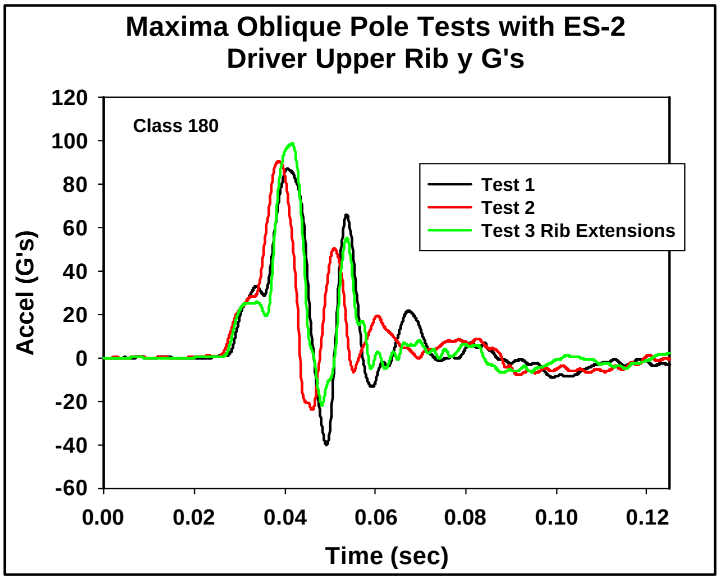
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Class 180
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Test 2
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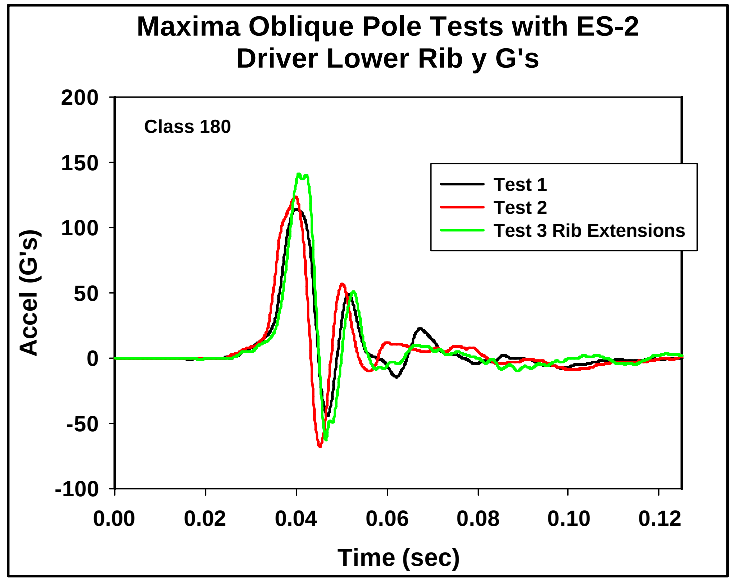
Accel (G's)
Time (sec)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Driver Lower Rib y G's
Class 180
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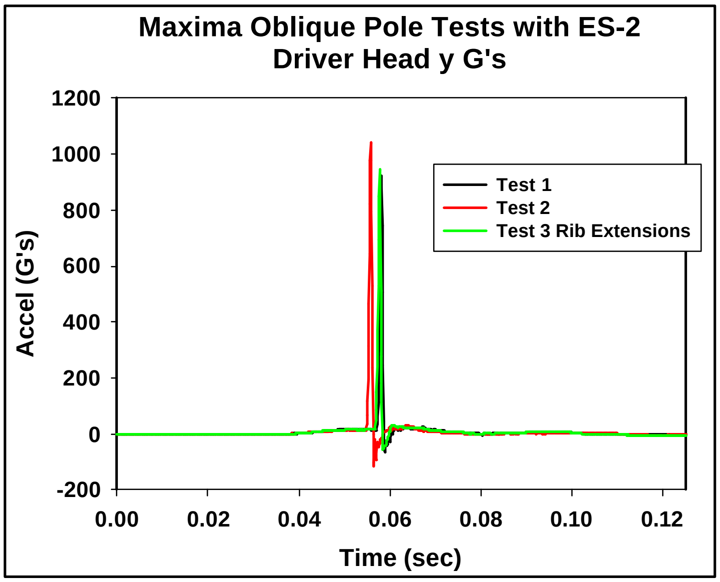
Test 2
Test 3 Rib Extensions
Accel (G's)
Time (sec)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Driver Head y G's
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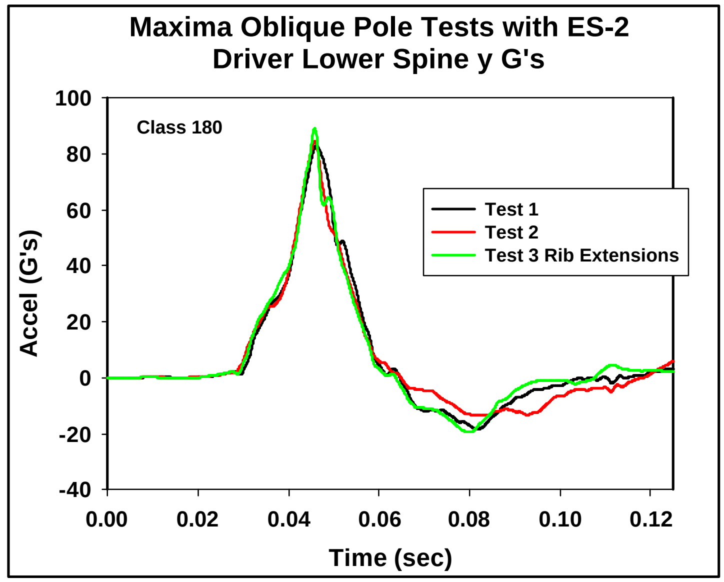
Accel (G's)
Time (sec)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Driver Lower Spine y G's
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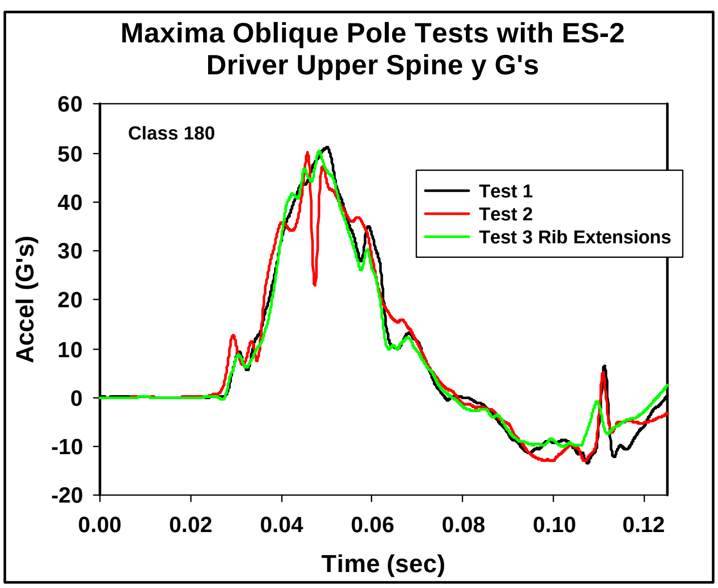
Time (sec)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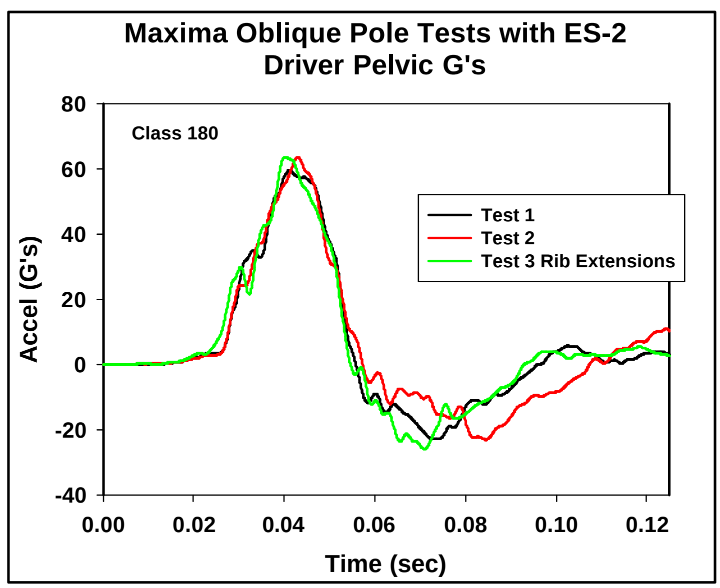
Accel (G's)
Time (sec)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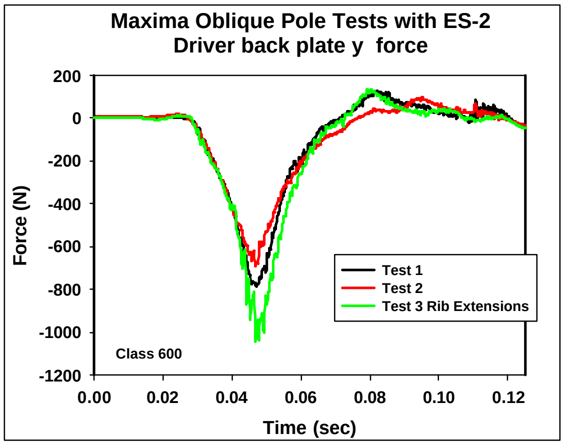
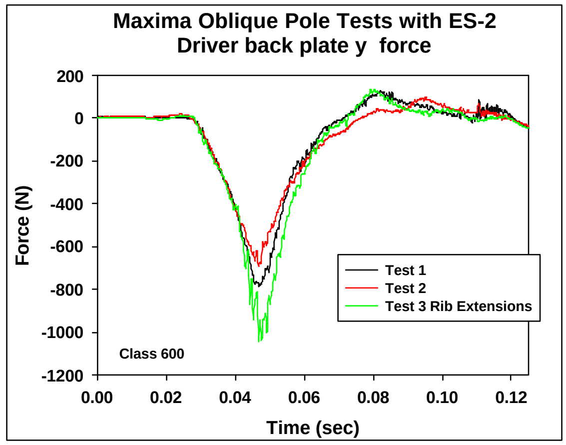
Accel (G's)
Time (sec)


Maxima Oblique Pole Tests with ES-2
Driver back plate y force
Force (N)
Time (sec)
Test 1
Test 2
Test 3 Rib Extensions
Class 600


Maxima Oblique Pole Tests with ES-2
Driver back plate y force
Force (N)
Time (sec)
Test 1
Test 2
Test 3 Rib Extensions
Class 600

X-.4. Conclusions

X-4.1 Summary of Finding Testing the ES-2

In the higher severity and fleet performance test series and additional component and sled tests with the ES-2, the research findings were as follows:

- ES-2 dummy demonstrated very good durability and overload capability;
- "Flat top" response in the ES-2 due to rib binding was resolved;
- Back plate to seatback frame interaction was found to be of concern: the frame of the seat back in some vehicle models can "catch/grab" the back plate and induce large back plate loads and off-load the thorax;
- Knee interactions during side impacts have virtually no effects on pubic symphysis peak loads (PSPF) and the resulting double peak spikes are of relatively low magnitude;
- ES-2 demonstrated the ability to detect risk of head injury. In pole tests, ES-2 head/neck/shoulder kinematics is comparable to the SID/HIII. Shoulder rotation did not to appear to be impeded in the tested crash test configurations;
- ES-2 demonstrated the ability to detect high abdominal loads due to an intruding armrest;
- ES-2 recorded considerably elevated thoracic and abdominal responses in some vehicles;
- In crash tests performed by NHTSA with the ES-2, large back plate loads were measured in two out of nineteen vehicle models tested, indicating considerable localized loading through the upper body back plate by the intruding seat back structure.

X.4.2 Summary of Finding Testing the ES-2 with Rib Extension Fix (ES-2re)

- Full scale crash tests of vehicles in the FMVSS 201P, 214, NCAP and high severity loadings showed that the ES-2 dummy with the rib extension fix (ES-2re) has resolved the back plate "grabbing" problem;
- In comparable full scale crash tests with the ES-2, the ES-2re dummy demonstrated nearly identical performance when seat back "grabbing" was not evident;
- While in some vehicles the back plate still senses loading from the seat back structure, the loading is caused primarily by a particular seat frame geometry rather than grabbing by the back plate;
- In those vehicles in which the localized back plate load path has been mostly eliminated, the momentum transfer, that was passed through the back plate with the ES-2, is now being directed mainly through the ribs and partly through the shoulder of the ES-2re. As a result, rib deflections are expected to increase;
- In oblique side impact pole tests and additional FMVSS 214 and US side NCAP tests, the durability of ES-2re and its good mechanical performance of the rib deflection system and back plate loading were further verified.
- The ES-2re demonstrated consistent performance and the ability to perform useful measurements under the most severe loading conditions.

Chapter XI Durability and Overload

XI.1 Durability of ES-2re:

No durability problems were experienced with the ES-2re (rib extension and modified back plate hardware) in the thirteen full-scale crash tests performed. The majority of the rib deflections were within maximum available deflection range. A series of 17 sled tests were also performed with the ES-2re during the same time frame. The sled tests included rigid and padded high-speed flat wall, rigid and padded low-speed flat wall, rigid low-speed thoracic, abdominal, and pelvic offset, and padded low-speed pelvic offset wall configurations. Also in 23 full-scale crash tests performed by NHTSA, the ES-2 has demonstrated very good durability. The only new parts acquired after the series of tests were as follows: shoulder foams, pelvis foam plugs, and a spare set of ribs. It is worth noting that the existing socket head screws on the clavicle load cell to the clavicle attachment were causing the shoulder foam cap to tear. Also, there was a tear in one of the abdomens although the dummy passed the abdomen impact calibration requirements.

XI.2 Overload

The ES-2 and the ES-2re performance in terms of undistorted or truncated measurements were found to be adequate in high severity F150-to-vehicle and IIHS MDB-to-vehicle crash tests, and in the higher-speed US NCAP side impact crash test environments. The majority of the rib deflections were within maximum available range. Maximum range was reached into two instances: 1) the driver upper rib deflection in the IIHS MDB-to-Cadillac De Ville crash test at US side NCAP speed and 2) the driver upper rib also in the US side NCAP test with LeSabre where both the door and hinge at A-pillar collapsed. However, since both deflections are considered well beyond the expected injury deflection threshold, and the measurements were not distorted, the ES-2re response was judges to be satisfactory.

Chapter XII Conclusions

The objective of this technical report is to provide technical data and knowledge that the agency has compiled in its extensive evaluation of the ES-2re dummy. The ES-2re dummy, with capabilities of measuring chest deflection, abdominal loading, and internal pelvis loads, is a useful test tool for assessing occupant protection systems in lateral impacts. This observation is based on data from evaluation of two sets of two ES-2re dummies used in certification, sled and full-scale crash tests. The test data indicate that the ES-2re rib extension design has successfully solved the "grabbing" problem that occurs between the dummy's upper torso back plate and some vehicle seat backs. The agency has demonstrated the absence of this phenomenon in thirteen vehicle crash tests with two ES2-re dummies, of which eight tests were conducted with dummies equipped with production rib extensions and modified back plate assemblies, and five tests were conducted with prototype versions.

Sled test data from the Medical College of Wisconsin (MCW) has demonstrated that the modifications to the dummy permit the ES-2re to retain the original EuroSID-1 and ES-2 biofidelity and performance response at the prescribed test conditions. Additional sled tests at the NHTSA Vehicle Research and Test Center and analysis of the resulting data substantiated the MCW findings.

The agency testing also confirmed the conclusions contained in the EEVC report asserting that "The ES-2 prototype as tested is superior to…..the EuroSID 1 and hence, a more appropriate test device for regulatory testing". The agency tests agree with the EEVC that important shortcomings of the EuroSID-1 have been satisfactorily addressed by the ES-2. Biofidelity of the ES-2 has not only been maintained, but in some areas even improved. The EEVC observed that overall test results in full-scale tests of the ES-2 with back plate modifications have increased rib deflections by some 17% even in cases where the flat top effects were not present. On the other hand, the pubic force has decreased by about 10% due to improved leg interaction. The EEVC report noted that contradicting results were observed with back plate loading involving seat back grabbing. ACEA advised that the ES-2 can be used as an interim alternative side impact test dummy harmonized for FMVSS 214 and ECE R95 purposes providing the remaining technical issues, primarily the back plate "grabbing" were satisfactorily resolved.

The agency evaluated the ES-2 as recommended by ACEA (Association of European Automakers) and found that localized back plate loading due to "grabbing" by the intruding seat structure is dependent on the seat back design and can substantially influence the amount of rib deflection. As noted above, the incorporation of the rib extension retrofit design has completely resolved the back plate-"grabbing" problem. Accordingly, the ES-2re will now be capable of producing more consistent and human-like ribcage loadings in full-scale vehicle crash tests, and thus facilitate the design of better occupant protection systems.

The evaluation of the ES-2re dummy indicated that:

1. The rib extension changes have added approximately 0.9 kg ((2 lb) to the weight of the torso without exceeding the allowed weight range variation for the torso assembly;

2. The dummy's calibration response stayed within the specified performance boundaries and exhibited excellent repeatability;

3. The sled tests indicate that the ES-2re overall responses compared well with the ES-2 responses. On the average, the data indicated slightly lower response forces on the lumbar, thoracic spine and pelvis, but increased thorax deflections by up to 10 percent.

4. Full scale testing demonstrated that the addition of rib extensions to the ES-2 dummy:
   - Minimizes the interaction effects of the dummy with the seat back and, thereby, reduce the transmission of loads from the seat back frame into the torso of the dummy to insignificant magnitudes, unless the seat back frame structure is of a design that interferes with the dummy's kinematics;
   - Reduces significantly, if not minimizes, the loading magnitudes and force distributions on the spine and the thoracic structure in those instances in which high localized back plate loading would have occurred with the ES-2 standard dummy;
   - Results in higher chest deflections (up to 20%) in instances where the back plate loading with the seatback would have occurred with the ES-2 dummy;
   - Does not affect the dummy's head, neck and shoulder kinematics in pole tests

5. The ES-2re dummy has virtually the same biofidelity as the ES-2 standard dummy;

6. The ES-2re as well as the ES-2 dummies demonstrated excellent structural durability and ability to withstand severe overloads while retaining the integrity of measurements.

7. Worldwide experience with the EuroSID-1 dummy, and the adoption of the ES-2 dummy with rib extension provisions by WP.29, offers the possibility of the ES-2re dummy becoming a truly harmonized side-impact crash test dummy for worldwide use.

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Attachment 1

First Technology
Innovative Solutions

ES-2
Eurosid-2 50th percentile side impact
Crash Test Dummy

User Manual
Guidelines for test-engineers and dummy technicians

February 2002

Attachment 2a

First Technology
Innovative Solutions

First Technology Safety Systems Inc.
47460 Galleon Drive
Plymouth
MI 48170, USA
Tel: +1 734 451 7878
Fax: +1 734 451 9549
Email: sales@ftss.com
Web: www.ftss.com

Progress Report

Pendulum Test Results of New ES2 Rear Rib

Date: 6/12/02

To:

Prepared by :
Dr. York Huang

1. Abstract

To enclose the rear gap of the ES2 rib cage, three rear ribs are added. A new backplate and a Teflon cover are used to retain the open end of the rear rib. Certification tests show that the ribs are still within certification corridors after modification. Pendulum tests have been conducted at 0°, -23° rearward and +18° forward angles. Rib deflection is quite smooth and there is no sign of resonant vibration. The peak deflection reduced by 4%-7% due to small friction force (180N). However, the friction angle is small (20°). In vehicle testing, when the direction of the resultant force from the rear rib has an angle (measured from Y-axis) of less than 70°, the rib deflection is not expected to decrease. In fact, more rib deflection is possible.

2. Introduction

High backplate force from ES2 is observed in NHTSA vehicle testing. The objective is to reduce backplate force by closing the gap between the ribs and the backplate. Pendulum tests were conducted to evaluate the dummy before and after rib modification. It should be noted these pendulum tests are not designed for Biofedelity testing. This document summarizes the test results of the new ES2 rear rib design.

3. Design

Three rear ribs are designed to enclose the rear gap, as shown in Figure 1. The curved end of the original rib needs to be cut-off (Figure 2).

Figure 1 ES2 additional rear ribs

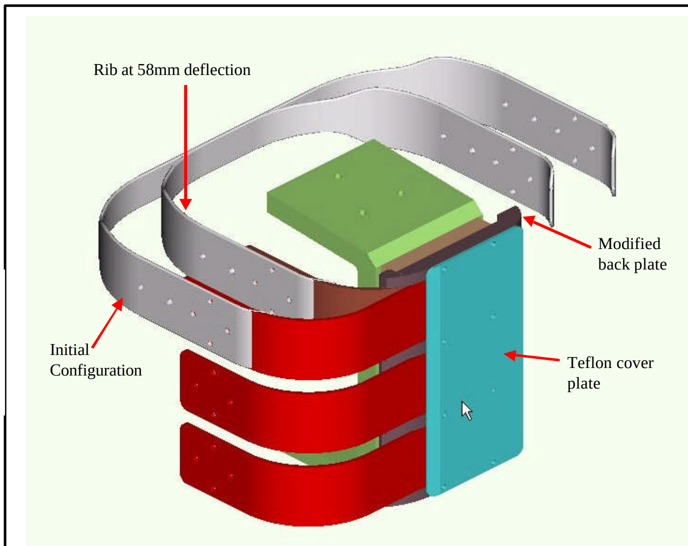
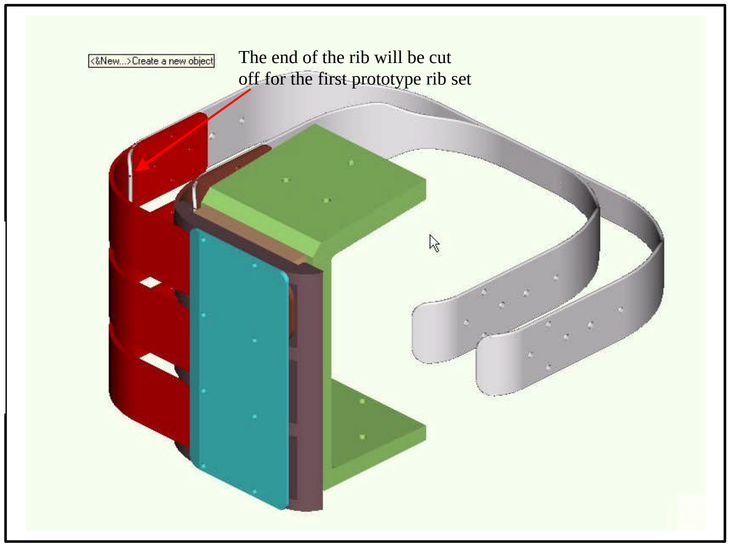


Figure 2 Interference due to the curved end



4. Certification Tests

A set of ES2 ribs is chosen for this study. The ribs were first certified in the rib drop tests at velocities of 2, 3 and 4m/s, per ES2 rib certification procedures. After the ribs were modified and were tested in the pendulum impacts at 0° and -23°, the same certification tests were also conducted. It is found that the ribs meet certification requirements before and after modification. Note that a new bracket is required to mount the modified rib to the drop tower to avoid interference. The certification results are summarized in Table 1.

Table 1 Certification results before and after rib modification

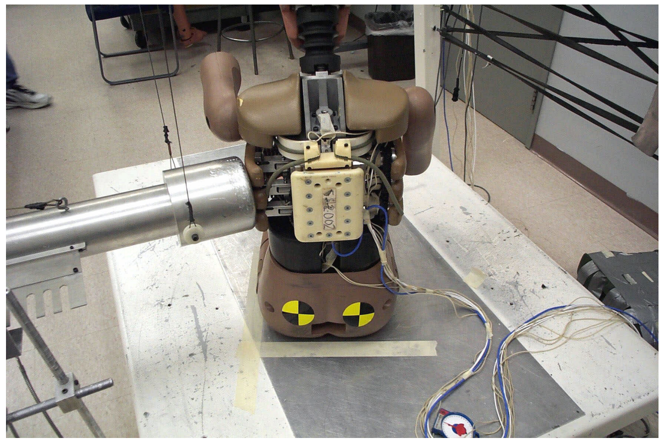
Rib#	2m/s (mm)		3m/s (mm)		4m/s (mm)	
	Before	After	Before	After	Before	After
97333	26.01	26.96	38.08	39.12	49.62	48.52
97318	25.11	27.30	38.13	38.54	49.38	49.79
97319	25.55	26.66	38.04	38.67	49.20	49.54

5. Pendulum Tests

5.1. Test Setup

The ES2 was subjected to pendulum impacts at three angles: 0°, -23°and +18°. Figure 3 shows the test setup for the -23° oblique impact.

Fig. 3 Test setup for an oblique impact



As shown in Figure 3, the Hybrid III 50th thorax pendulum was used. The pendulum weighs 50 lbs. The velocity of the pendulum is set to 6.25 m/s so that the rib deflection is close to 50mm. In order to re-position the dummy accurately, the skin jacket was removed. There was no Teflon sheet between the dummy pelvis and the table so that the dummy position can be marked on the table. The pendulum centerline is 4.9mm above the centerline of the middle rib. The 4.9mm offset distance was due to the removal of the Teflon sheet without re-adjusting the pendulum height. The pendulum height was adjusted in Tests 35423 through 35426 so that the pendulum center is in line with the center of the middle rib.

In the 0° impact, the center of the pendulum is in line with the centerline of the piston. In the -23° rearward impact, the dummy is positioned so that the pendulum center line points to the rear screw hole (for mounting rib to piston), as shown in Figure 4.

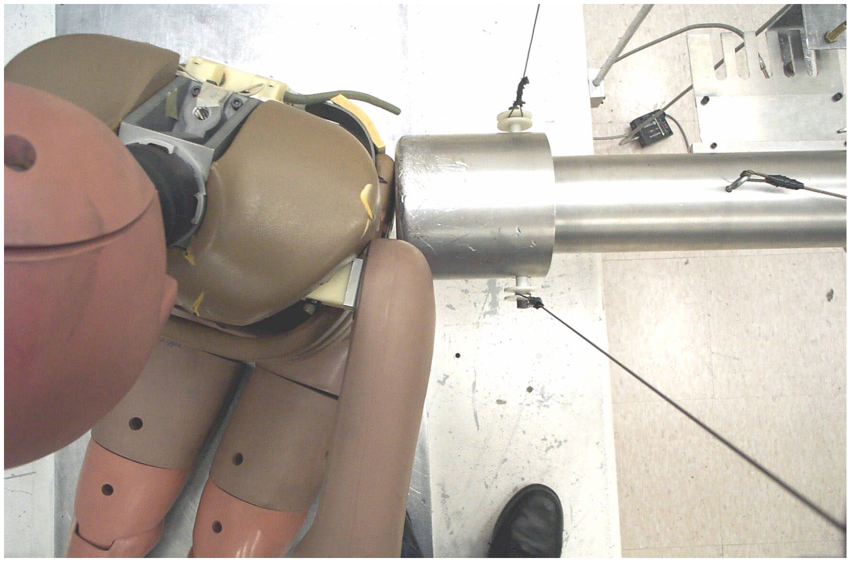


Figure 4 Top view of oblique impact setup

5.2. Test Results – Summary of Rib Deflections

The pendulum test results of 0°, -23°and +18° impacts are summarized in Tables 2 through 4. In the baseline test, the standard ES2 ribcage (no rib modification) is used. All three ribs have similar deflection (49mm) for both of 0° and -23° impacts.

When the pendulum impacts the dummy at a forward (+18°) angle, the rib foams of all three ribs got damaged. Therefore, only three tests were conducted: one was the baseline test by removing the rear ribs, and the other two tests had the rear ribs and Teflon cover.

Table 2. Rib deflections from pendulum impacts to ES2 at 0°

Test#	Description	Impact Angle	Top Rib (mm)	Mid Rib (mm)	Low Rib (mm)
35411	Baseline	0°	48.38	49.04	48.68
35412	Baseline	0°	47.82	48.75	48.66
35415	Modified rib with Teflon cover	0°	47.33	48.19	45.57
35416	Modified rib with Teflon cover	0°	47.09	47.38	44.32
35417	Modified rib without Teflon cover	0°	48.17	48.60	46.20
35418	Modified rib without Teflon cover	0°	47.59	48.64	46.57
35423	Modified rib with Teflon cover, align pendulum center to rib center	0°	47.67	48.71	47.06
35426	Modified rib without Teflon cover, align pendulum center to rib center	0°	47.36	48.83	47.85

Table 3 Rib deflections from pendulum impacts to ES2 at -23°

Test#	Description	Impact Angle	Top Rib (mm)	Mid Rib (mm)	Low Rib (mm)
35413	Baseline	-23°	49.31	49.26	49.38
35414	Baseline	-23°	49.95	49.29	48.60
35421	Modified rib with Teflon cover	-23°	46.88	46.69	46.52
35422	Modified rib with Teflon cover	-23°	47.74	47.52	45.66
35419	Modified rib without Teflon cover	-23°	47.20	47.56	45.67
35420	Modified rib without Teflon cover	-23°	48.04	46.91	46.44
35423	Modified rib with Teflon cover, align pendulum center to rib center	-23°	46.22	47.47	47.11
35426	Modified rib without Teflon cover, align pendulum center to rib center	-23°	45.99	46.76	45.86

Table 4 Rib deflections from pendulum impacts to ES2 at +18°

Test#	Description	Impact Angle	Top Rib (mm)	Mid Rib (mm)	Low Rib (mm)
35625	Baseline, No rear rib	+18°	39.33	44.28	41.01
35623	Modified rib with Teflon cover	+18°	39.52	45.41	40.74
35424	Modified rib with Teflon cover	+18°	38.25	44.19	41.15

As shown in the above tables, it can be concluded that:

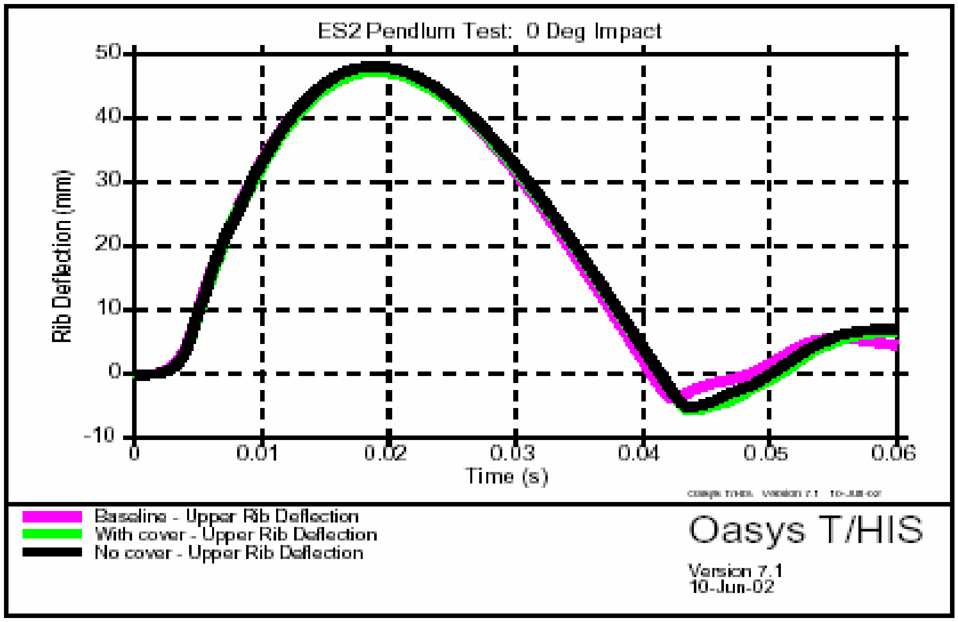
- Teflon cover does not have observable effect to rib deflection.
- After the ribs are modified, upper and middle ribs have about 2mm or 4% less deflection.
- After the ribs are modified, lower ribs have about 3.5mm or 7% less deflection.
- After the ribs are modified, the lower rib has about 1.5mm less deflection than the upper and middle ribs. However, when the dummy is raised 4.9mm such that the pendulum center is in line with the centerline of the middle rib (Tests 35423 through 35426), all three ribs have similar deflection for the same test conditions. Therefore, the lower rib does not appear to be abnormal.
- When the pendulum is set a forward (+18°) angle, the data from modified rib matches those of the baseline quite well, although the deflection is less than that of the impacts at 0° and -23°.

5.3. Test Results –Time-History Data

Figures 5 through 9 show the rib deflection, backplate forces Fx and Fy for the pendulum impact at 0°.

Figures 10 through 16 show the rib deflection, backplate forces Fx and Fy and rib acceleration for the pendulum impact at a rearward angle of -23°.

Figures 17 through 22 show the backplate, inertia and friction forces, for the analysis of friction forces and friction angles.



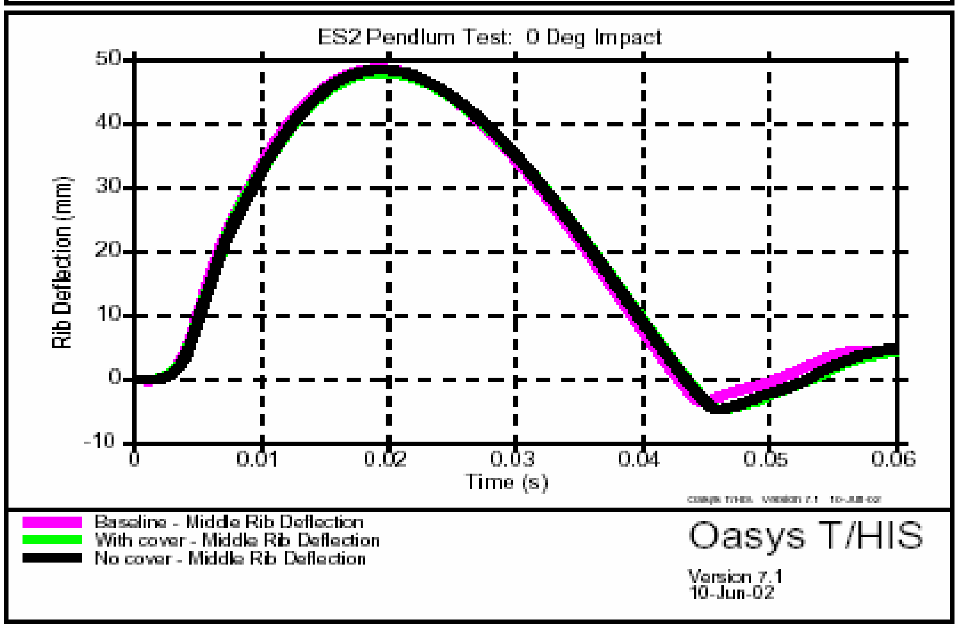


Figure 5 (Top) Comparison of top rib deflections of Baseline, with or without Teflon cover for a pendulum impact at 0°

Figure 6 (Bottom) Comparison of middle rib deflections of Baseline, with or without Teflon cover for a pendulum impact at 0°

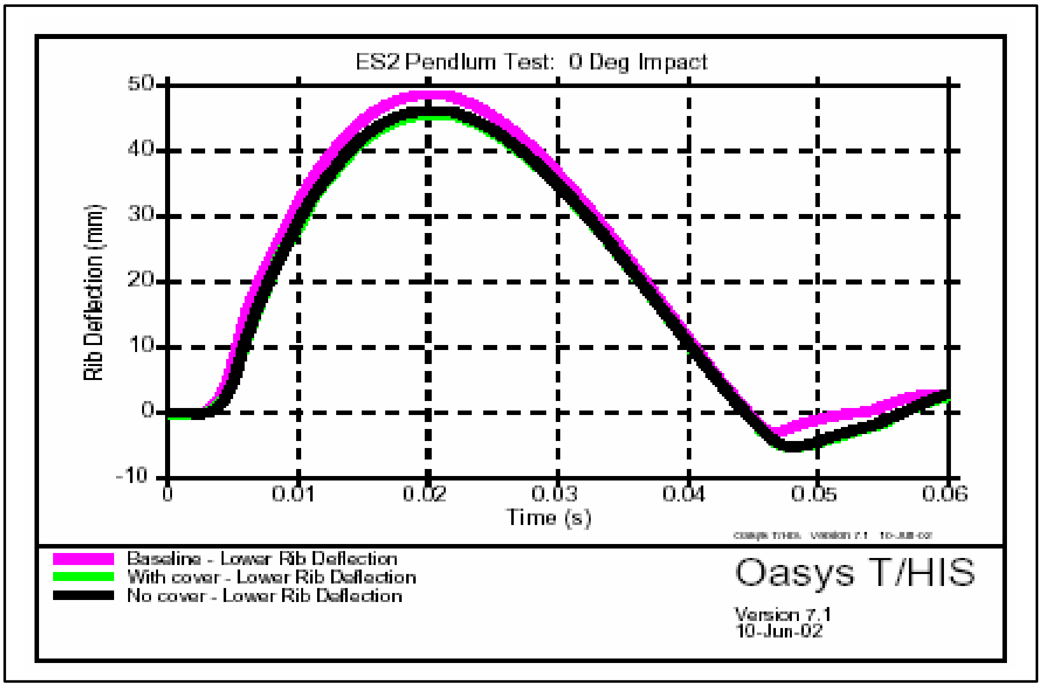


Figure 7 Comparison of lower rib deflections of Baseline, with or without Teflon cover for a pendulum impact at 0°

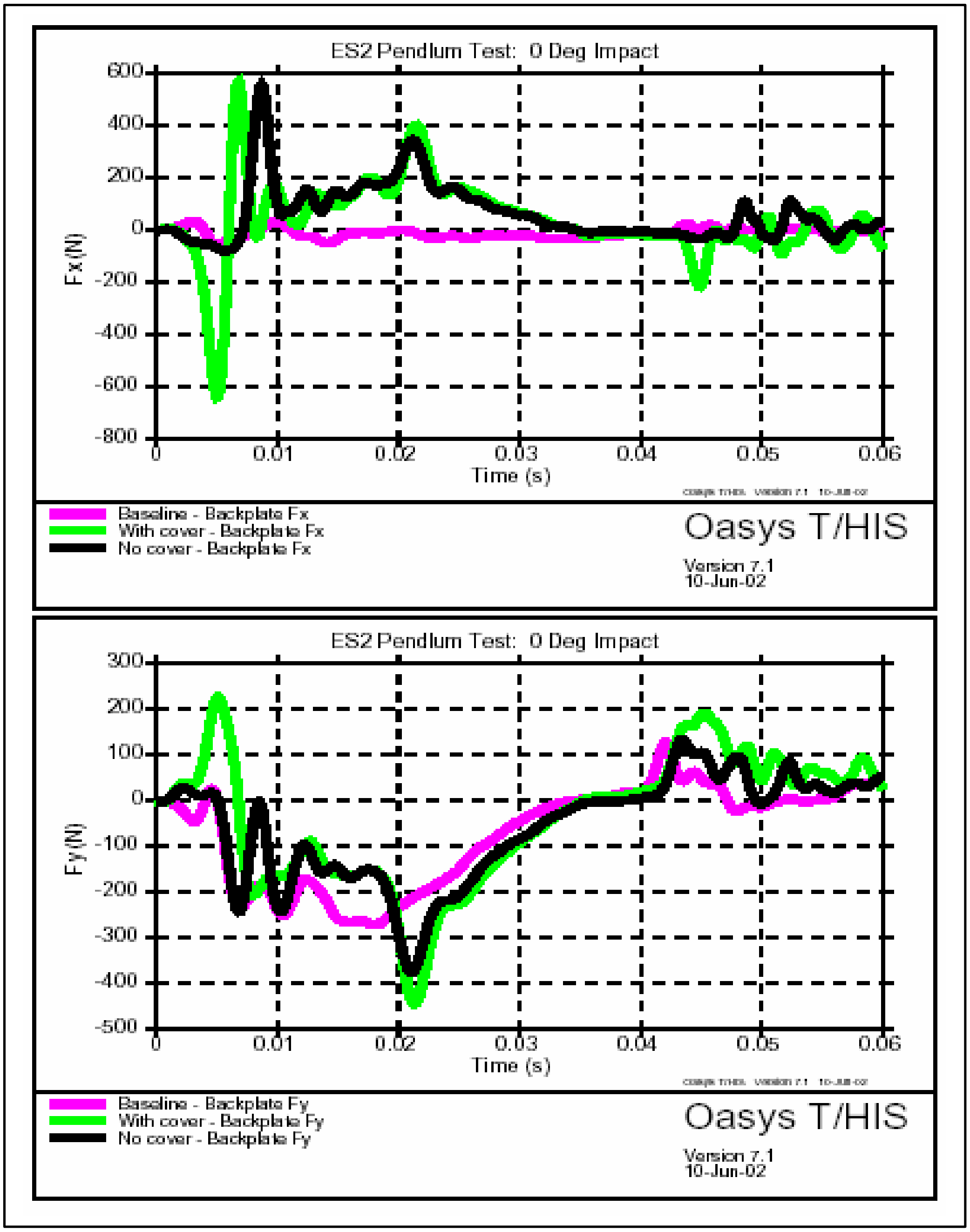
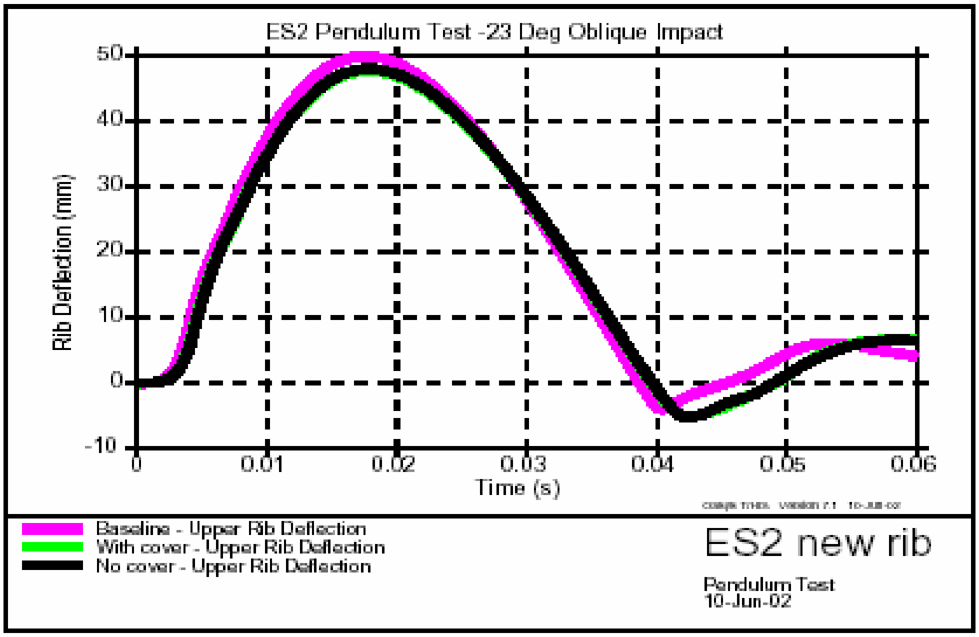


Figure 8 (Top) Comparison of backplate Fx of Baseline, with or without Teflon cover for a pendulum impact at 0°

Figure 9 (Bottom) Comparison of backplate Fy of Baseline, with or without Teflon cover for a pendulum impact at 0°



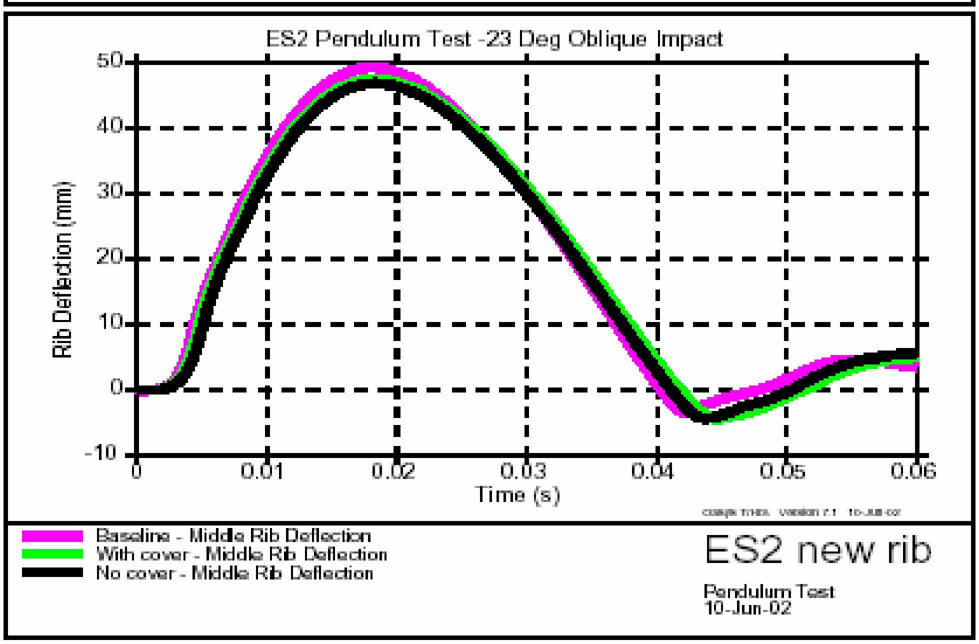


Figure 10 (Top) Comparison of top rib deflections of Baseline, with or without Teflon cover for a pendulum impact at -23°

Figure 11 (Bottom) Comparison of middle rib deflections of Baseline, with or without Teflon cover for a pendulum impact at -23°

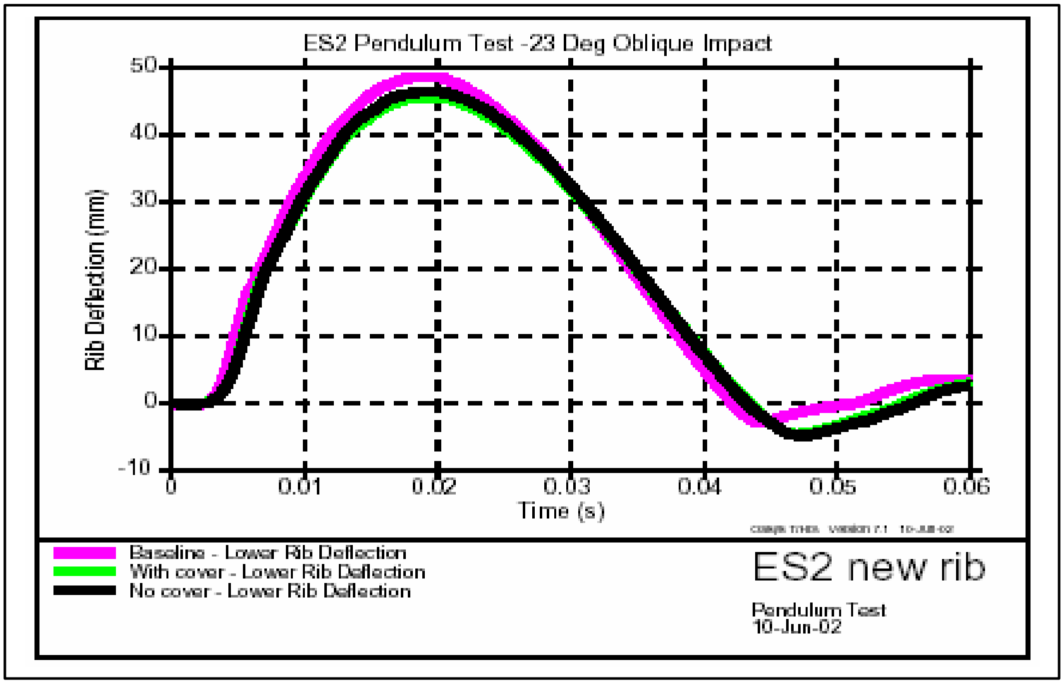


Figure 12 Comparison of lower rib deflections of Baseline, with or without Teflon cover for a pendulum impact at -23°

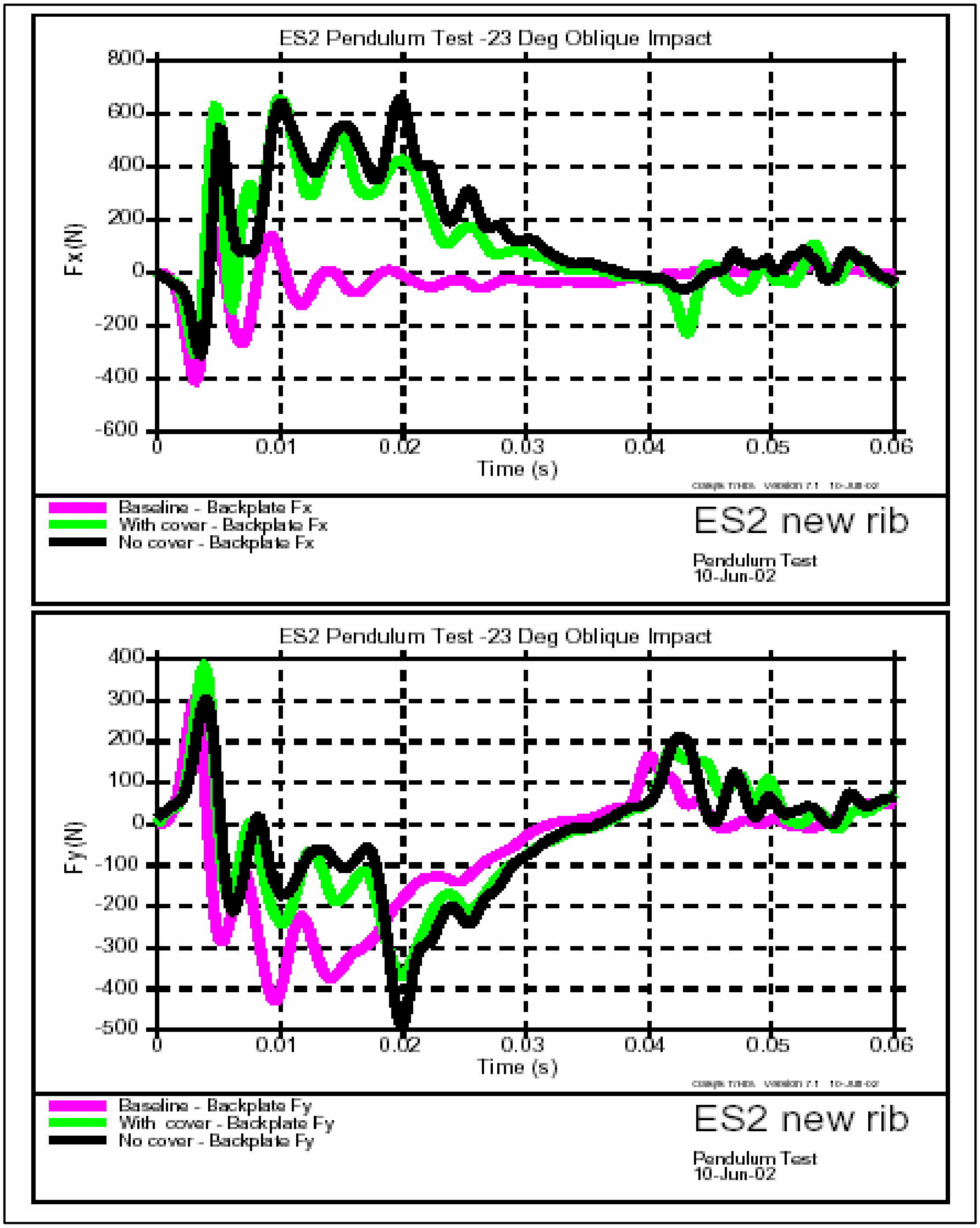


Figure 13 (Top) Comparison of backplate Fx of Baseline, with or without Teflon cover for a pendulum impact at -23°

Figure 14 (Bottom) Comparison of backplate Fy of Baseline, with or without Teflon cover for a pendulum impact at -23°

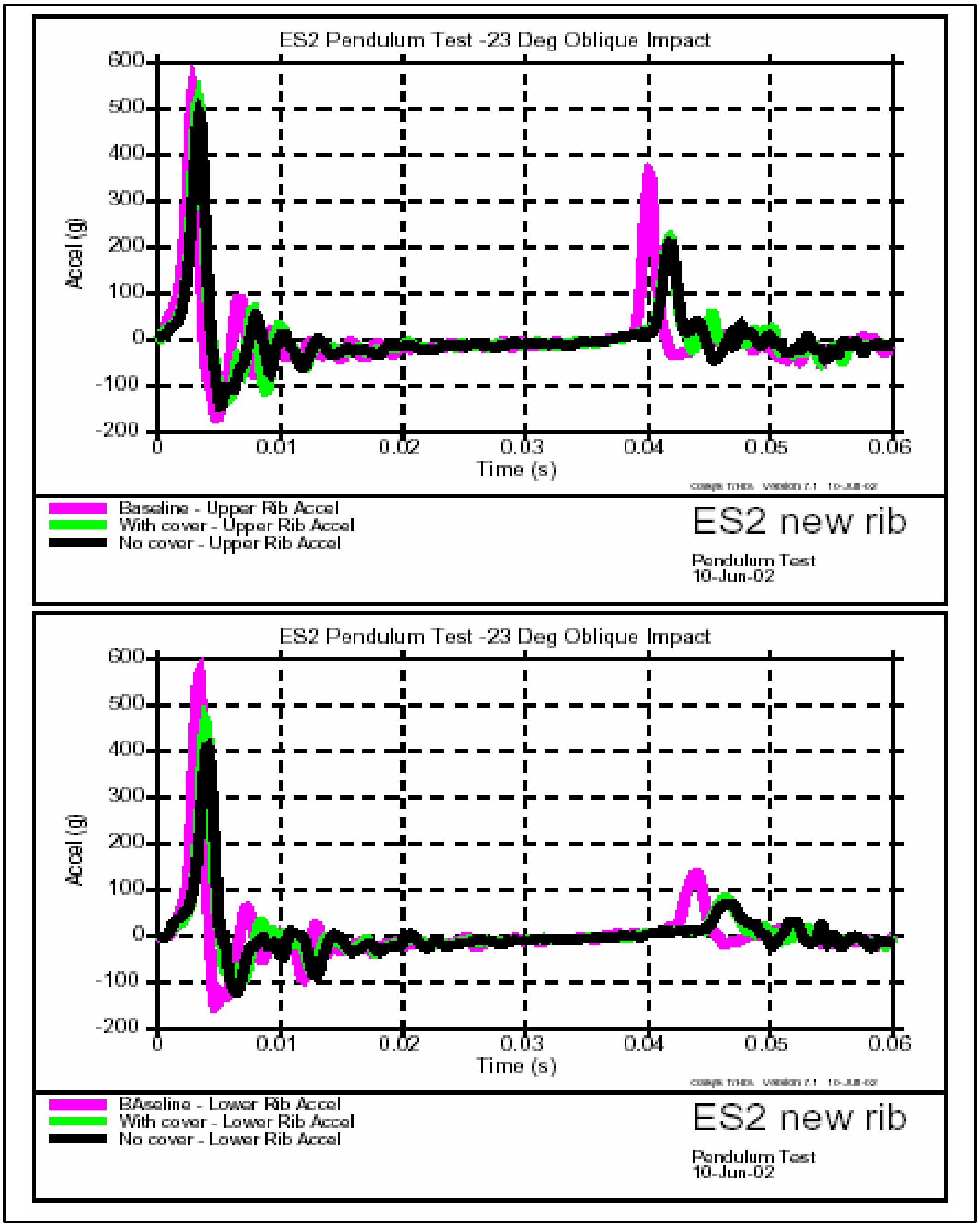
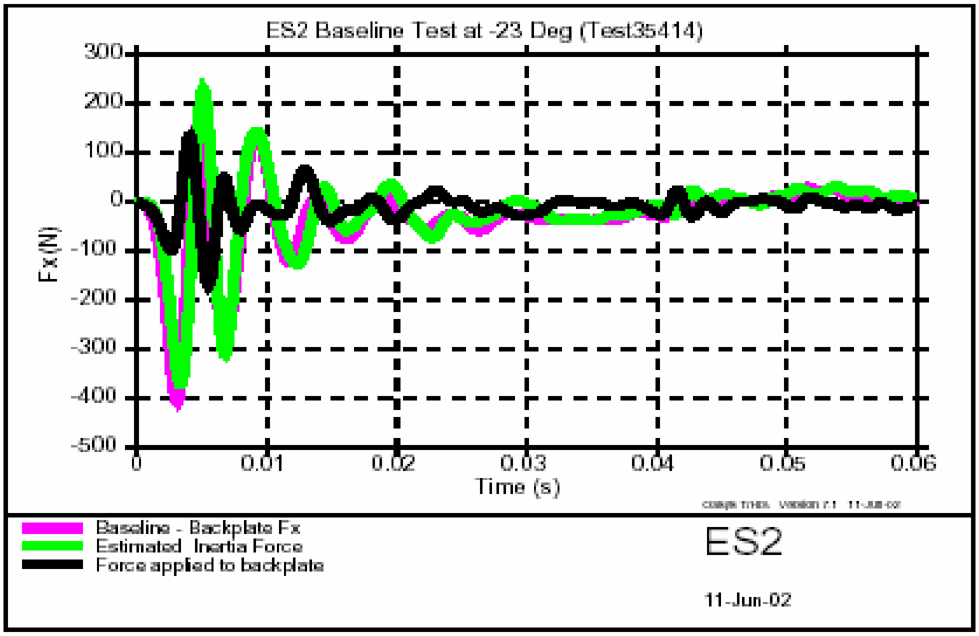


Figure 15 (Top) Comparison of top rib acceleration of Baseline, with or without Teflon cover for a pendulum impact at -23°

Figure 16 (Bottom) Comparison of lower rib acceleration of Baseline, with or without Teflon cover for a pendulum impact at -23°



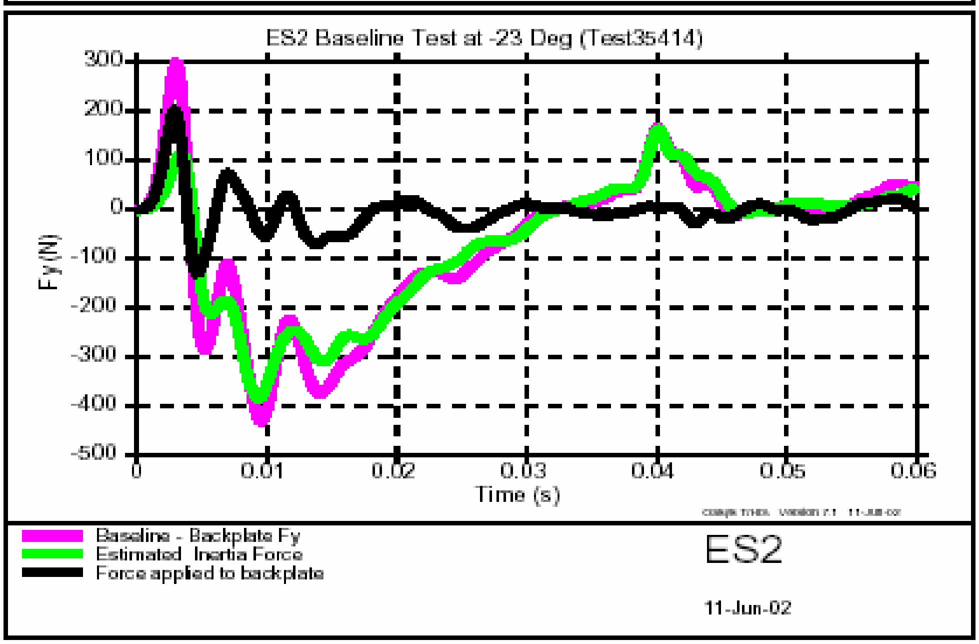
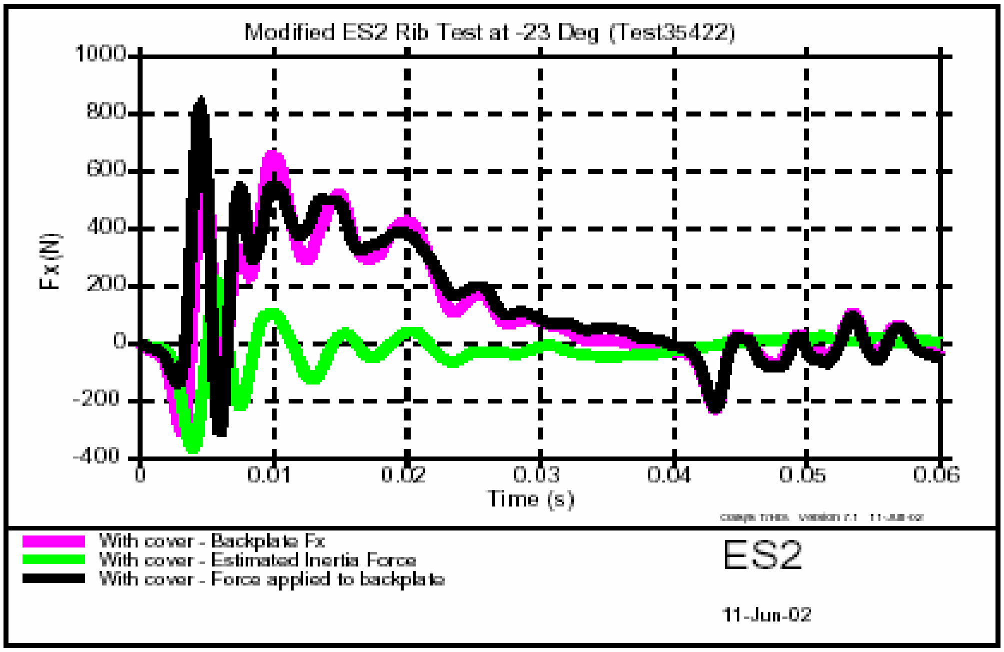


Figure 17 (Top) Estimation of inertial force and the force applied to the backplate in X direction for the baseline oblique test at -23°

Figure 18 (Bottom) Estimation of inertial force and the force applied to the backplate in Y direction for the baseline oblique test at -23°

Note that there should be no force applied to the backplate since there is no rear rib in the baseline test. Due to the error in estimating the acceleration, therefore, the small force (applied to backplate), as shown in Figures 17, is due to the error in estimating the inertial force. See discussion for detail



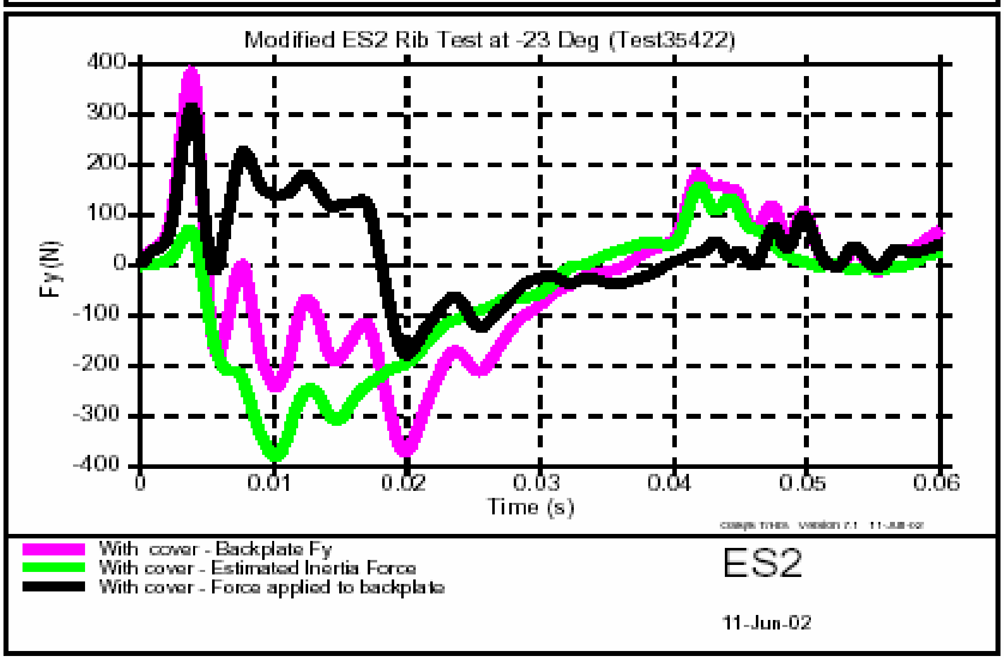


Figure 19 (Top) Estimation of inertial force and the force applied to the backplate in X direction for the baseline oblique test at -23°

Figure 20 (Bottom) Estimation of inertial force and the force applied to the backplate in Y direction for the baseline oblique test at -23°

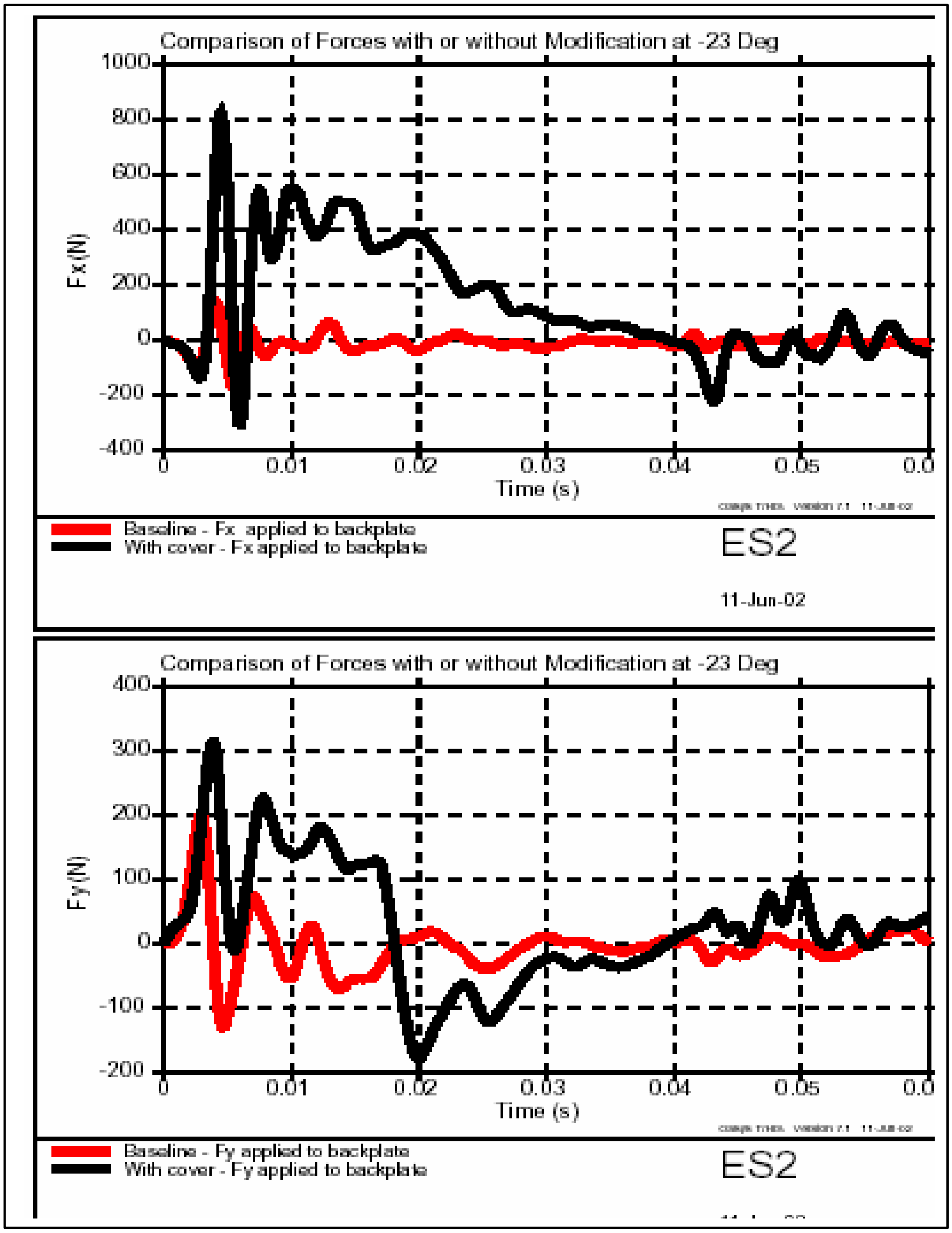


Figure 21 (Top) Comparison of the applied force to the backplate in X direction for baseline test and the test with modified rib and Teflon cover, in oblique tests at -23°

Figure 22 (Bottom) Comparison of the applied force to the backplate in X direction for baseline test and the test with modified rib and Teflon cover, in oblique tests at -23°

Note: There should be no force in the baseline test since there are no rear ribs. The force shown for baseline test is due to estimation error of the acceleration at c.g. of the backplate loadcell.

6. Discussion and Summary

- The rib deflections are quite smooth and no "flat topping" is observed for the tests.

- The rib acceleration does not show resonant vibration due to the open rear rib configuration, as shown in Figures 15 and 16.

- The actual forces (Fx and Fy) that are applied to the backplate will be equal to the difference between the force measured by the loadcell and the inertia force from the weight of the loadcell. Fx is the normal force and Fy is the friction force. The weight of the outer portion of the loadcell and backplate is estimated to be 12.5N (2.8lbs). The acceleration is assumed to be the average of T1 and T12 accelerations. The inertia force will be equal to the product of the average acceleration (in g's) and the weight (12.5N). In the baseline test (Figures 17 and 18), the calculated force that is applied to the backplate is small, except for the first peak. Note that there should be no force applied to the backplate since there is no rear rib in the baseline test. The calculated forces for the test with modified rib are shown in Figures 19 and 20. Figures 21 and 22 shows the comparison of the forces that are applied to the backplate due to the rear ribs. The friction force Fy reverses its sign (from positive to negative) during the rebound phase at T=20ms. When the first peak is ignored, Fx and Fy are about 500N and 180N, respectively. Therefore the effective friction coefficient will be equal to 180/500 or 0.36 and the friction angle is $\tan^{-1}0.36 = 20°$. In other words, the rib will not "lock" for an oblique impact at a rear angle up to 70° (90°-20°).

- Although friction between the rear rib and backplate is small (180N Fy), the rib deflection is reduced by 4% to 7% due to the rear ribs. Note that the pendulum type of testing has fixed input energy for a given velocity and small friction will have effect on the rib deflection. However, in the vehicle test, small change to the dummy will have no effect on the kinematics of the side door. Therefore, the side door can be considered to have infinite energy when comparing to the small friction between the rear rib and the backplate. It is reasonable to assume that the rib deflection of the modified ES2 will not decrease in a vehicle test. In fact, the rib defection is expected to increase due to the larger contact area from the rear ribs, when the resultant force from the vehicle has a rearward angle of less than 70°.

Attachment 2b

First Technology
Innovative Solutions

First Technology Safety Systems Inc.
47460 Galleon Drive
Plymouth
MI 48170, USA
Tel: +1 734 451 7878
Fax: +1 734 451 9549
Email: sales@ftss.com
Web: www.ftss.com

Progress Report

ES2 Rib Extension Refinement

Date: 6/27/02

Prepared by :

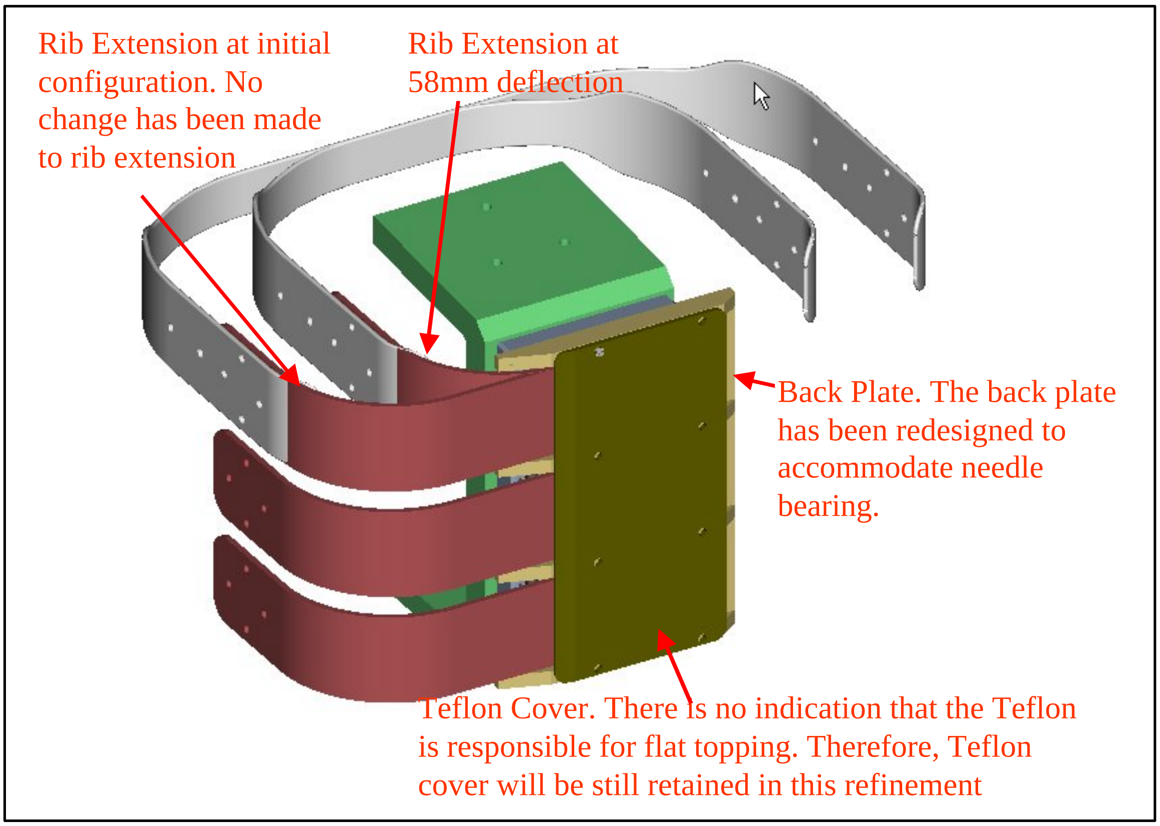
Dr. York Huang

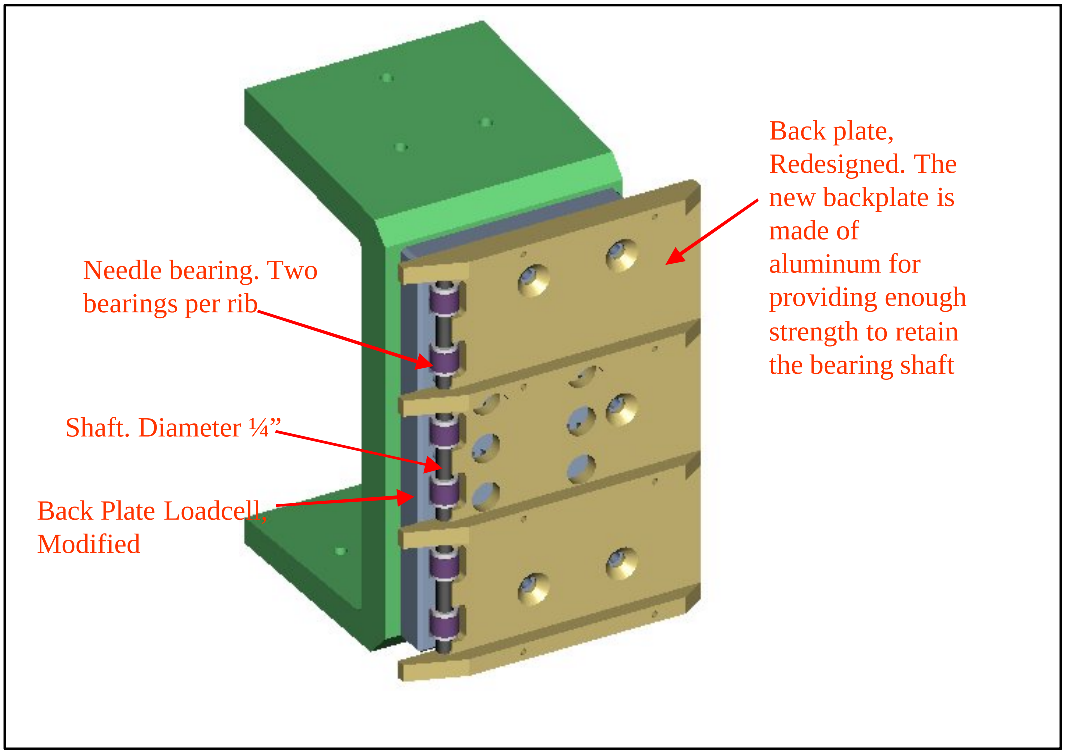
1. Introduction

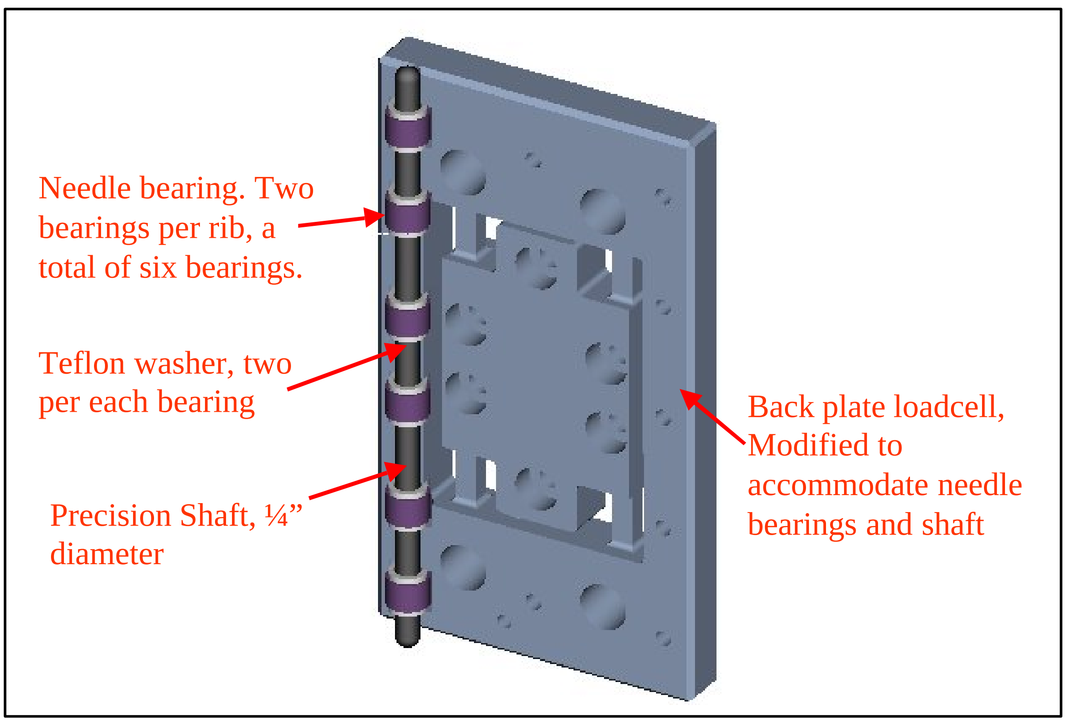
On June 21, 2002, NHTSA conducted a crash test using an ES2 with rib extensions. Steve Moss summarized FTSS observations and conclusions in his email dated June 24. Back plate force Fy is decreased from 11.4kN to 1.6kN. The rib deflection has increased significantly, between 21% to 56%. Therefore, the rib extensions work per design intention. There is concern on “flat topping” due to the reversal of the friction force from positive to negative. Therefore, refinement of the design is required to address this concern. This report summarizes the upgraded design of rib extension to reduce or eliminate friction force with needle bearings.

2. Design

The new design of the rib extension assembly is shown in the following Figures.




Back plate,
Redesigned. The
new backplate is
made of
aluminum for
providing enough
strength to retain
the bearing shaft
Needle bearing. Two
bearings per rib
Shaft. Diameter ¼”
Back Plate Loadcell,
Modified


Needle bearing. Two
bearings per rib, a
total of six bearings.
Teflon washer, two
per each bearing
Precision Shaft, ¼”
diameter
Back plate loadcell,
Modified to
accommodate needle
bearings and shaft

3. Fabrication Schedule

We are targeting to finish all machine work by July 20. Modification to a back plate load cell will be finished at the same time.

4. Evaluation Program

4.1. Replication of "Flat Topping" as Seen in Vehicle Test

The ES2 rib cage with the existing rib extension assembly will be subjected to drop impacts at various impact angles to the rib extension. If the impact angle is 0° (in Y axis), flat topping should not be expected since there is no normal force (Fx). If the impact angle is 90° (in X axis), there will be no rib deflection. However, this phenomenon can be interpreted as "flat topping" with 0mm rib deflection. Therefore, "flat topping" due to friction, in theory, can be generated at about 45mm rib deflection by changing impact angle.

4.2. Verification of the Rib Extension Refinement

Once the flat topping is observed for the existing rib extension assembly per Section 4.1, the same test will be conducted for the upgraded rib extension assembly with needle bearing. Direct comparison can be made between the existing and the upgraded designs.

4.3. Test Schedule

The design and fabrication of the fixture will be finished by July 20. Evaluation tests will be done by July 30.

Attachment 2c

First Technology Safety Systems Inc.
47460 Galleon Drive
Plymouth
MI 48170, USA
Tel: +1 734 451 7878
Fax: +1 734 451 9549
Email: sales@ftss.com
Web: www.ftss.com

Progress Report

Pendulum Test Results of New ES2 Rear Rib

Date: 8/12/02

To:

Prepared by :

Dr. Ali Elhagediab
Dr, York Huang

INTRODUCTION:

The ES2 rib performance has improved with the addition of new rib extensions. The details of the new design and the significance of rib improvement have been detailed in previous reports. Despite this improvement, NHTSA has observed the occurrence of a “flat topping” phenomenon in the rib deflections. Friction between the rib extensions and the surface of the spinal load cell has been postulated to be the cause of the “flat topping”. In this report a series of tests were performed on the original and improved rib extension designs to show the efficacy of the new design. The new design incorporates needle bearing structure into the load cell to reduce friction between its surface and the rib extensions (see report titled “ES2 Rib Extension Refinement (6/12/02)” for more details).

TEST PROCEDURE & RESULTS:

Drop tests were designed to compare results from the two designs.

The drop test consisted of a drop tower and a rigid mounting fixture as shown in figure 1. The mass of the drop impactor was 8.09 kg with an interface diameter of 152 mm. A series of tests were performed on a one rib in the original design without the needle bearing to replicate the “flat topping” phenomenon. The rib was attached to the spine and tested at approximately 4.9 m/s (1.2 m height). The rib was rigidly fixed at angles of 0, 15, 30, and 45 degrees and tested with and without foam on the ribs (1” thick Ensolite). The only test that provided a rib deflection behavior that may be described as “flat topping” was the 45 degrees and foam interface test. The same test was performed on a single rib with the new design (with the needle bearing (NB)). Results are shown in figure 2. Rib displacement was increased by 18 % and friction reduced to minimal for the new design.

Three ribs were also tested in the drop fixture at 45 degrees with a foam interface similar to the single rib drop test (figure 3). The impactor was raised higher to provide similar rib deflections to those in the single rib test (3 m; 7.7 m/s). Results for the new and old design are shown in figure 4. Average rib displacement was increased by approximately 11 % and friction reduced by 60% for the new design.

CONCLUSION:

The new design with needle bearing significantly reduced friction between the rib extensions and the back of the spine, produced higher rib deflections, and reduced what appears to be “flat topping” in the rib deflections

Figure 1: Single rib test setup.

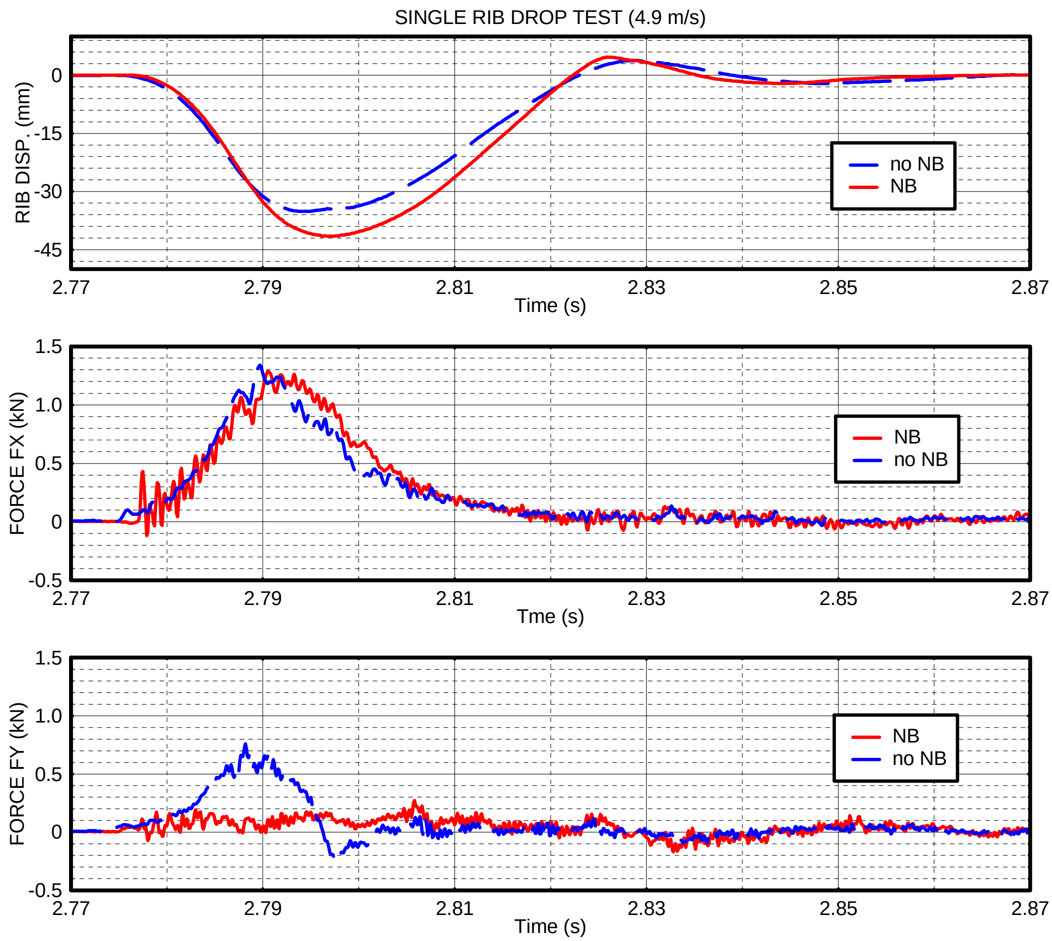


Figure 2: Rib deflections and normal (FX) and friction (FY) forces in a single rib drop tests for the designs with and without the needle bearing (NB).

Figure 3: 3 rib test setup.

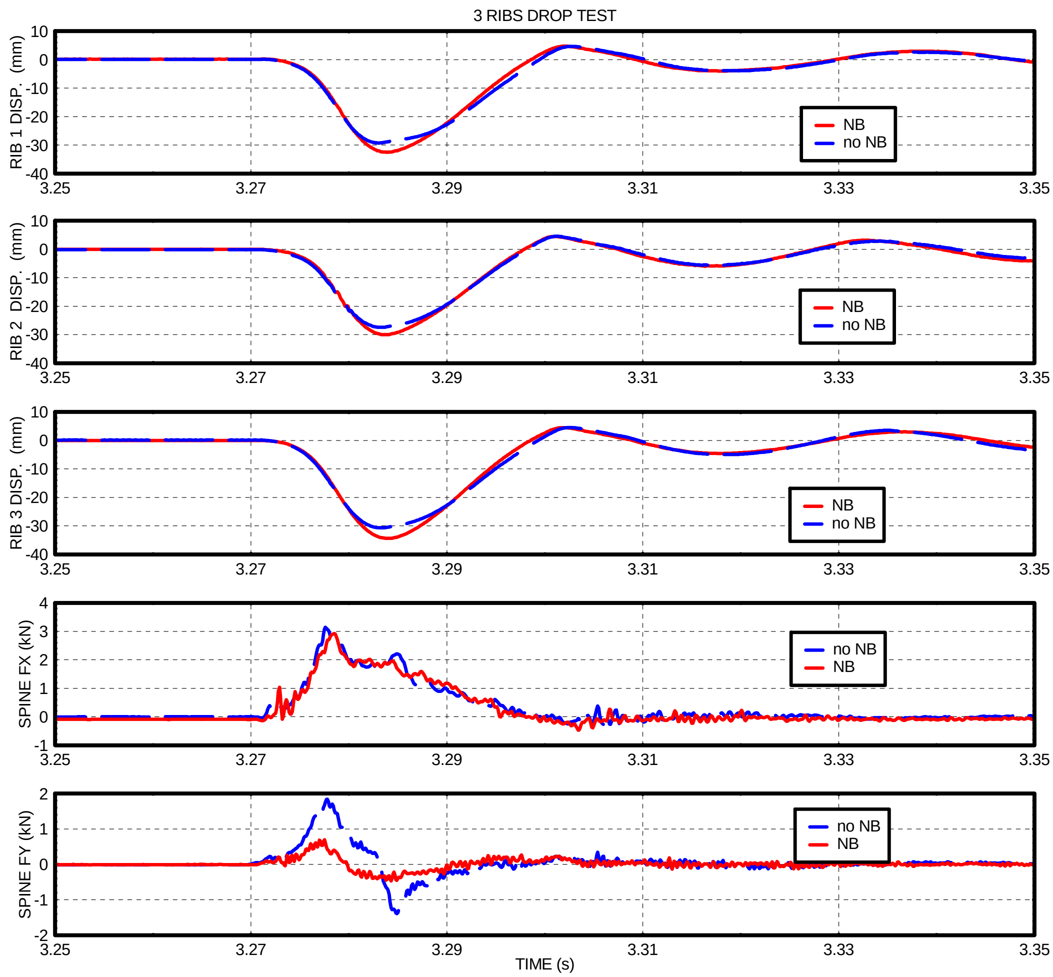


Figure 2: Rib deflections and normal (FX) and friction (FY) forces in three rib drop tests for the designs with and without the needle bearing (NB).

Attachment 2d

First Technology Safety Systems Inc.
47460 Galleon Drive
Plymouth
MI 48170, USA
Tel: +1 734 451 7878
Fax: +1 734 451 9549
Email: sales@ftss.com
Web: www.ftss.com

Progress Report II

Pendulum Test Results of New ES2 Rear Rib

Date: 8/14/02

Prepared by :

Dr. Ali Elhagediab
Dr. York Huang

TEST PROCEDURE & RESULTS:

Pendulum tests were designed to compare results from the two designs (with and without needle bearing (NB). A large database was collected from these tests. However, this short report will only show tests relevant to our conclusion.

In these tests the full dummy was seated on a stage as shown in figures 1 and 2. A 152 mm diameter 23.4 kg pendulum was used to impact the dummy at a 45 degrees angle centered at the middle rib and the corner of the rib extensions (left side). In most tests, the dummy was instrumented with the rib linear potentiometers, spine loadcell, upper and lower spinal accelerometers, and two rotational velocity transducers (Rx, and Rz) mounted on the top of the spine box behind the neck bracket. The pendulum was also instrumented with an accelerometer. As in the case of the drop tests, pendulum impact with foam padding produced what appeared to be “flat topping” from both, the old and new rib extension designs. Rib displacement results from two representative tests are shown in figure 3. The new design shows more rib displacement by approximately 6.4 % as an average for the three ribs. The corresponding spine load cell FX and FY and the effective friction force FFY are shown in figure 4. FX is slightly higher in the new design (6%) but FY and FFY are significantly lower (by 46 and 45 %, respectively). However, what resembles “flat topping” is still evident in the new design.

Extensive testing has eliminated the following as a source of the perceived “flat topping”: the damper, the pendulum interaction with the abdomen, and the friction between the surface of the impactor and the ribs. We believe that the rotation of the rib cage around a critical angle of 45 degrees have caused this effect (border line between effectively loading the ribs from the side or the back of the dummy). Under these conditions we believe that the pendulum interacts with the ribs in a linear and angular modes that cause double impacts. The second impact happens as the ribs are in the rebound phase thus prevented from free recovery. This causes what resembles “flat topping” but is not related to the similar phenomena observed in the drop or full vehicle tests.

We were able to change the shape of the deflection curves by changing the effective stiffness of the rib extensions. Two rib extensions were stacked and rigidly attached at each rib level to create the stiffer effect. Also rotational sensors were used to measure spinal rotation RZ. The signal was integrated to obtain the angular displacement. Rib displacement results are shown in figure 5 for a standard pendulum test and stiffened rib extensions test (all with needle bearing and 1” Insulite foam interface). The stiffened rib test shows a reduction in the perceived “flat topping”. This is caused by reduction of the peak pendulum acceleration of the second impact and the slight de-synchronization of the maximum rib deflection timing and the second pendulum impact. Figure 6 shows the pendulum accelerations for the two tests as well as angular velocities and angular displacements. Both tests show a maximum spinal angular rotation of approximately 7°. This effectively means that at the time of maximum rib deflection, the impact angle is 52°(effective -38° from the back). Figure 7 shows the pendulum accelerations and the rib deflections for rib 1 (positive values for clarity). In the standard rib extension test the second peak pendulum acceleration is approximately 31.5 g and occurs almost at the peak deflection, thus showing a “flat topping” resemblance. In the stiffened rib extension test, the second peak pendulum acceleration is approximately 25.5 g. This occurs because more energy is consumed in the first impact of the stiffened rib extensions versus the standard rib extensions (max. pendulum acceleration = 57 g & 46 g, respectively). Also, the peak rib deflection and the second pendulum acceleration peak are 3 ms apart in the stiffened rib extension test. This causes the deflection not to show “flat topping” resemblance.

Therefore, we conclude that the perceived “flat topping” resulted from these tests is a function of the rotation of the upper torso and pendulum second impact (due to real loading) and not related to a deficiency in the performance of the ribs.

Figure 1: Side view of the test setup.

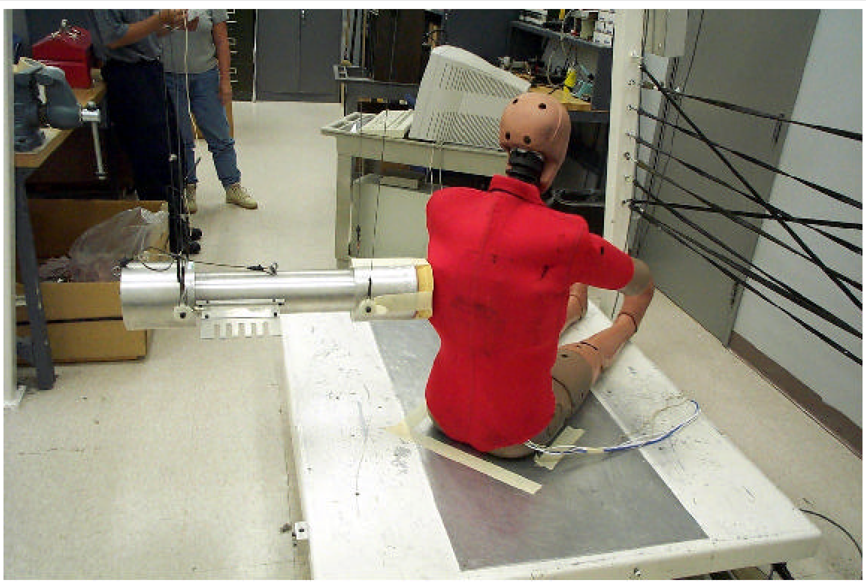


Figure 2: Rear view of the test setup.

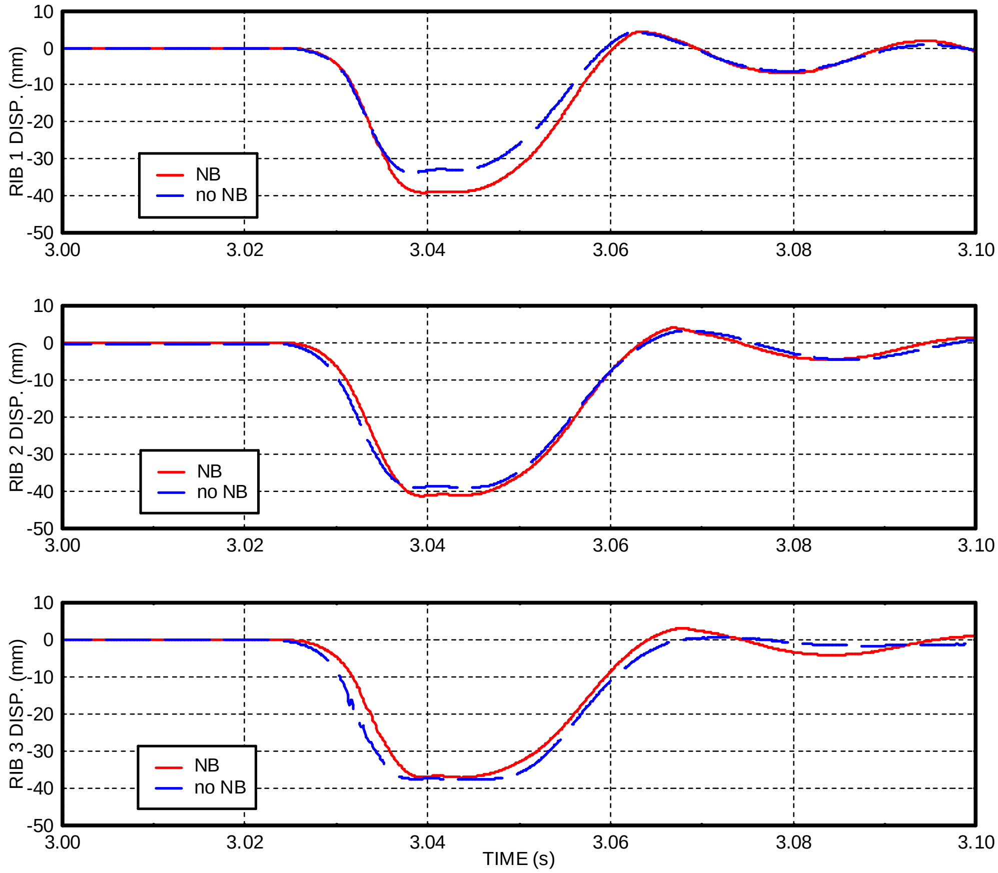


Figure 3: Rib deflections due to a pendulum impact with and without needle bearing (NB) design.

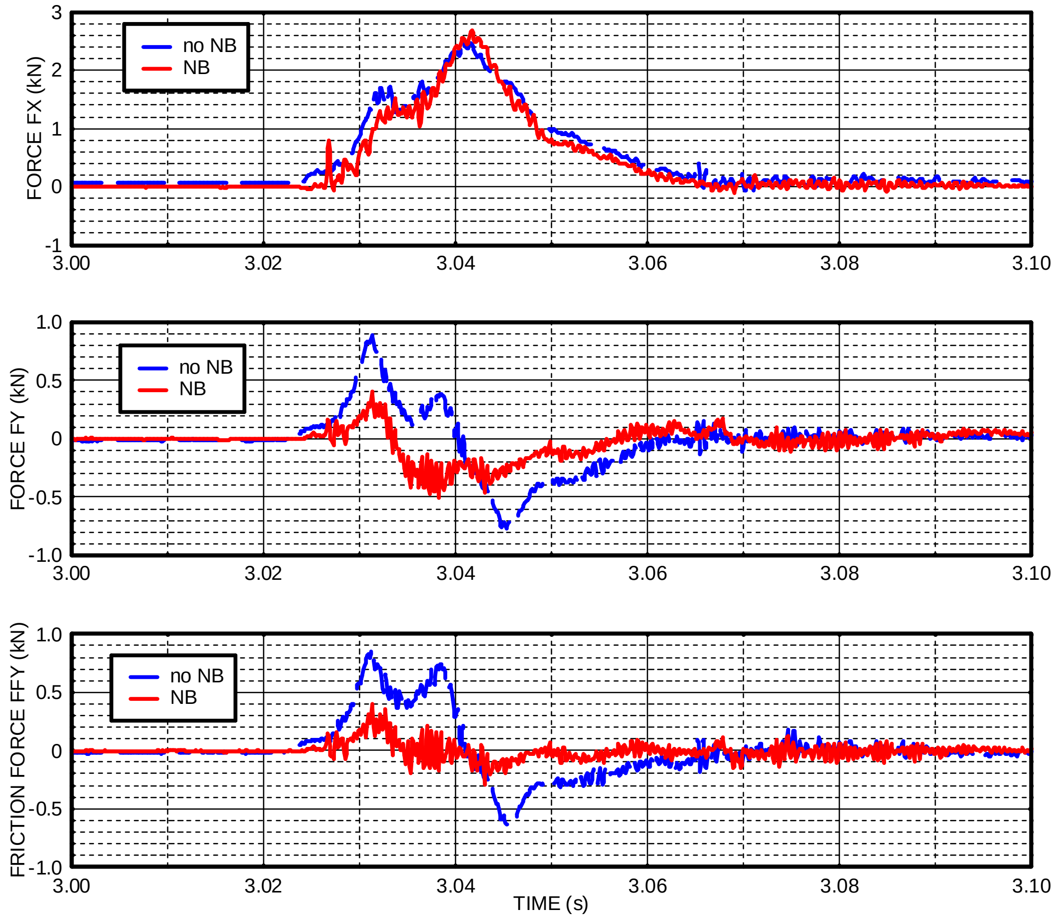


Figure 4: Spinal load cell measurements and calculated friction force for pendulum tests with and without the needle bearing (NB) design.

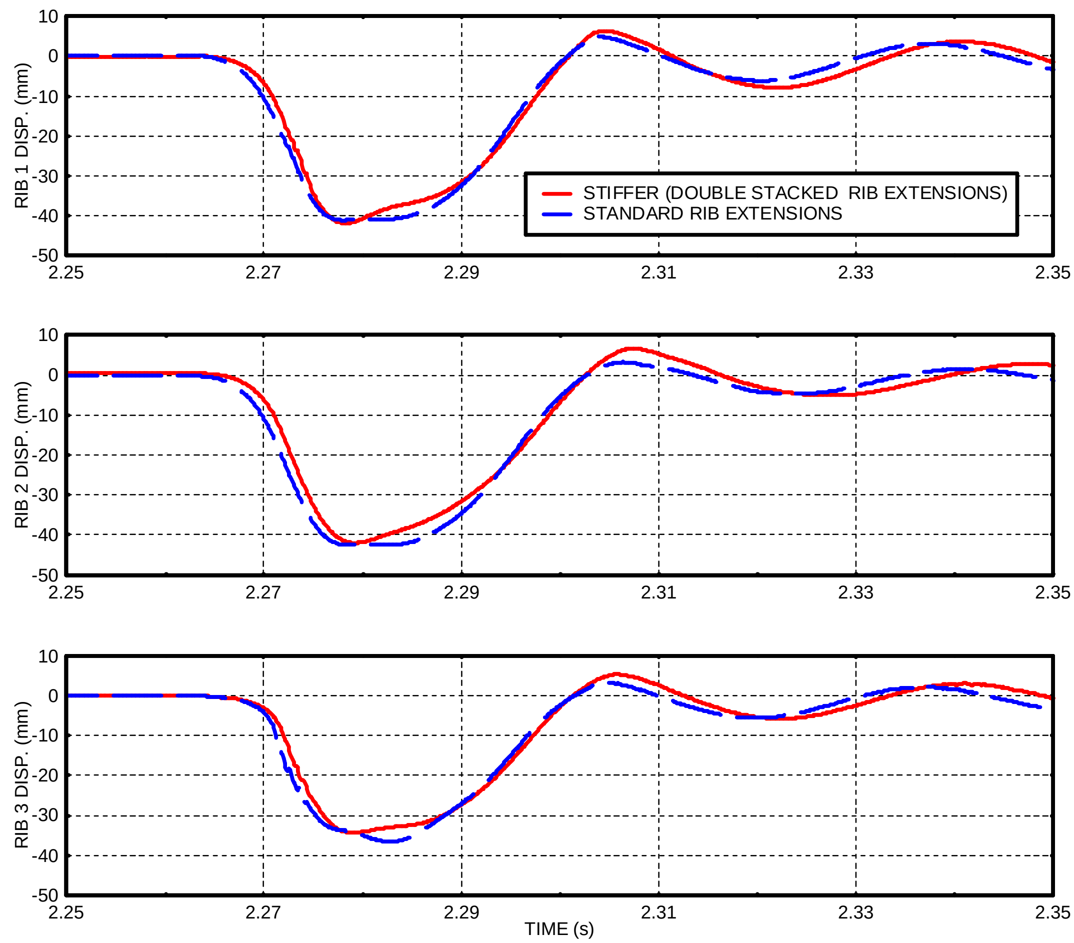


Figure 5: Rib deflections for standard rib extensions and double stacked rib extensions.

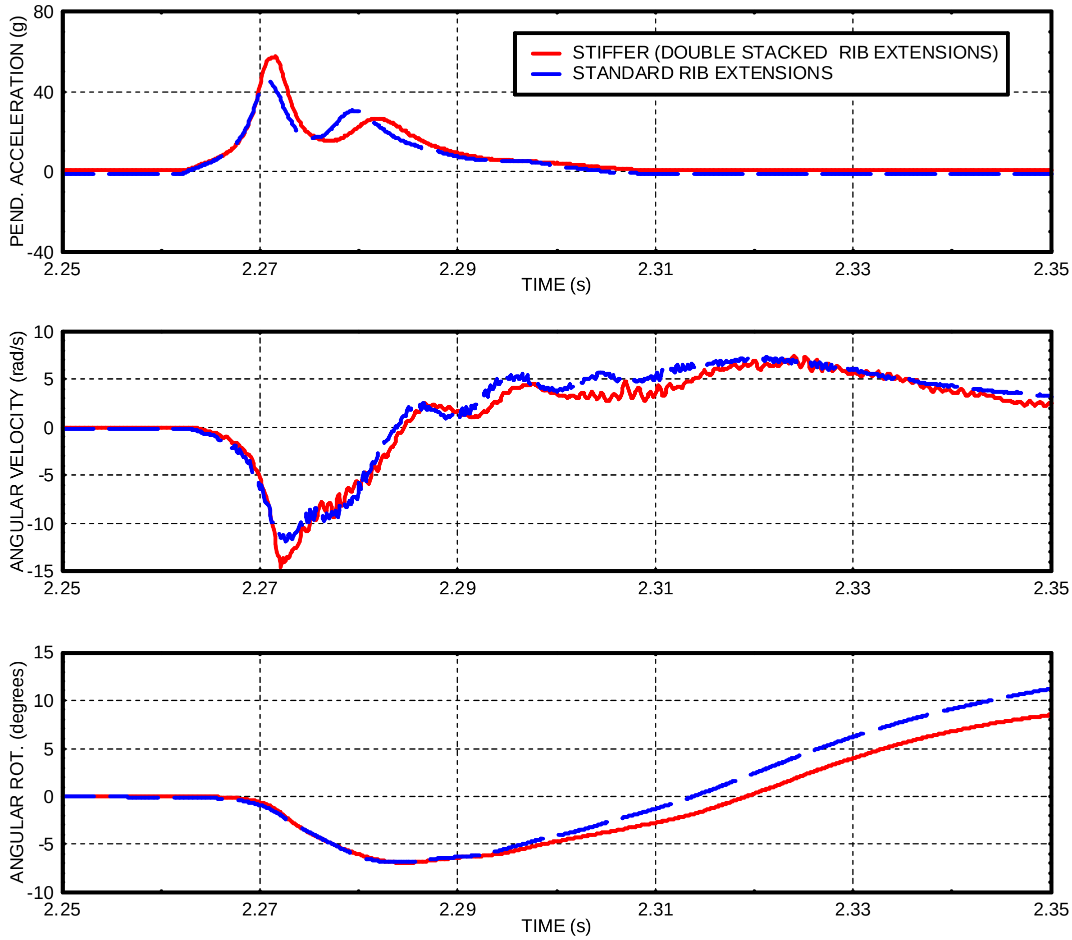


Figure 6: Pendulum accelerations, upper spine angular velocities and angular displacements for standard and stiffened rib extensions tests.

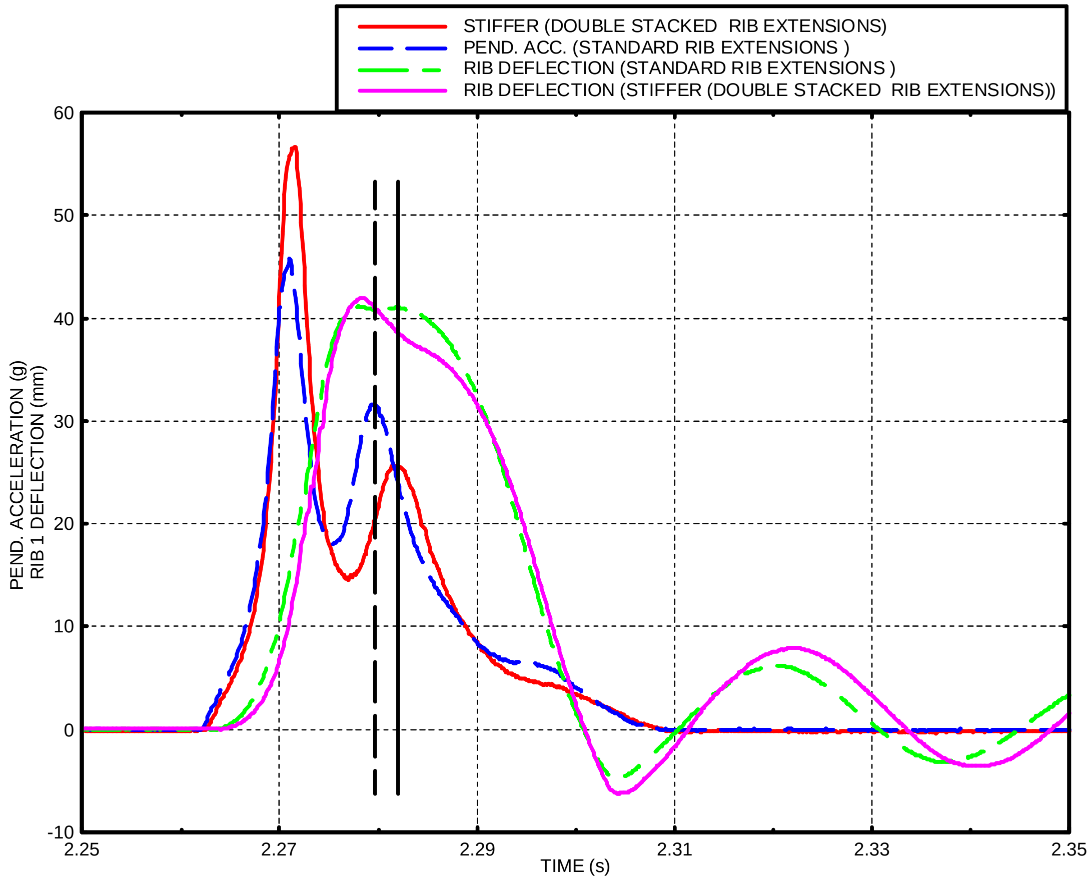


Figure 7: pendulum accelerations and rib deflection responses for standard and stiffened rib extensions.

Attachment 2e

First Technology Safety Systems Inc.
47460 Galleon Drive
Plymouth
MI 48170, USA
Tel: +1 734 451 7878
Fax: +1 734 451 9549
Email: sales@ftss.com
Web: www.ftss.com

Progress Report III

Analysis of ES2 Rib Extension – Finite Element Approach

Date: 10/4/02

Prepared by :
Dr. York Huang
Dr. Ali Elhagediab

Introduction

ES2 Rib extension with needle bearing has been proposed to reduce lateral back plate loading. Drop and pendulum tests have been conducted to evaluate the effectiveness of the new rib extension. The test data were summarized in the previous progress reports [1,2,3]. It is found that the needle bearing reduces the friction between the back plate and the rib extension to negligible level. The rib deflection increases by 10-20% for a drop test to the rib for the rib module with needle bearing. In the oblique pendulum test at a lateral-posterior angle of 45° (or -45°), there is a delay for the rib to rebound after reaching its peak. The change of rib deflection is small after peak deflection for about 10ms. It was theorized that the rib deflection has double peaks due to double impacts from the pendulum. The second impact from the pendulum prevents the rib from rebounding instantly. Since the terminology “flat-topping” is quite misleading, “double-peaks” will be used to describe this phenomenon in the following analysis.

To further prove the “double-peaks” assumption, finite element analysis has been conducted. The simulation results are summarized in this report.

MODEL DESCRIPTION

The ES2 model with rib extension is obtained by modifying the FAT ES2 model. The modification and analysis were mainly conducted by DYNAMORE, the LS-DYNA distributor in Germany. The model consists of 69,000 nodes and 170,000 elements. The test setup and the modified ES2 model are shown in Figures 1 and 2. The pendulum weighs 23.4kg and has an initial velocity of 6.7m/s. The needle bearing is modeled by zero-friction between the rib extension and the back plate.

Figure 1. Oblique pendulum impact to ES2 at -45°

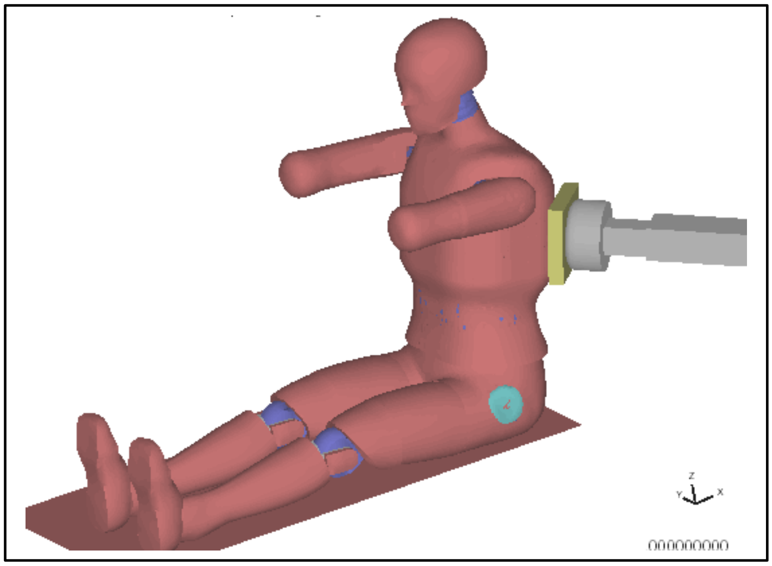


Figure 2. Finite element model of ES2 with rib extension

SIMULATION RESULTS

The animation is shown in the attached AVI files (whole dummy, top and rear views). The top and rear views are shown in Figures 3 and 4. Figures 5 through 10 shows the correlation of rib deflections, back plates forces Fx and Fy and pendulum acceleration.

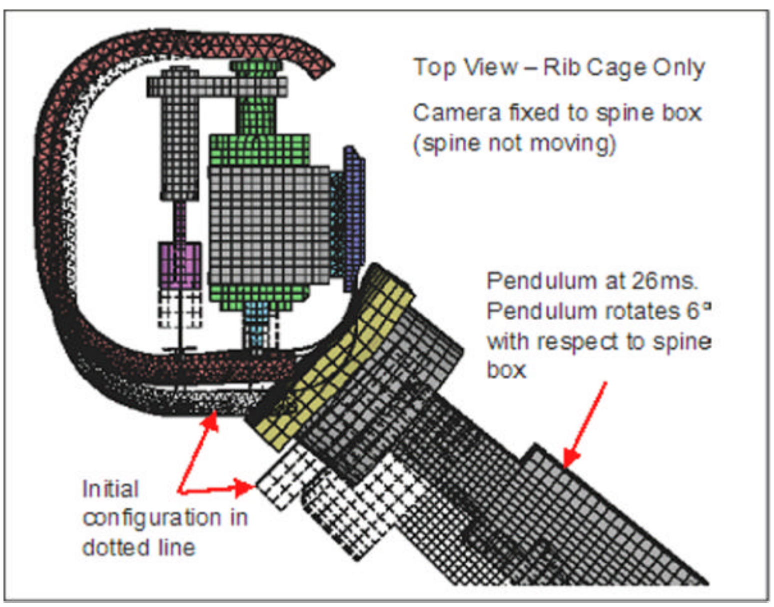


Figure 3. Top view at 26ms

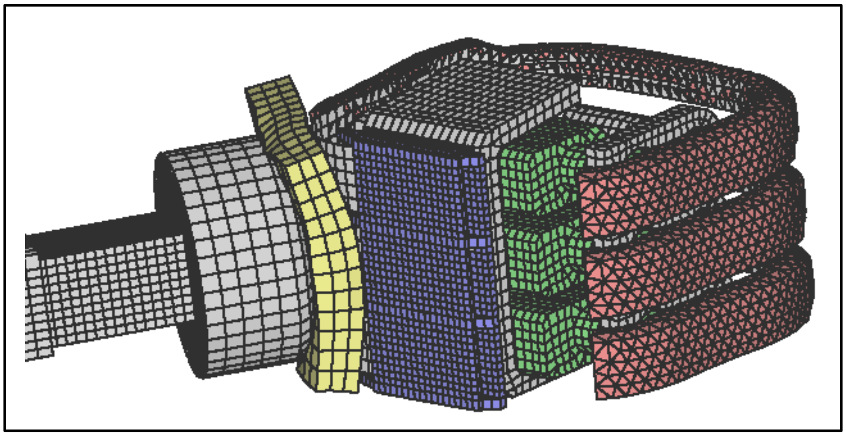


Figure 4. Rear view at 26ms

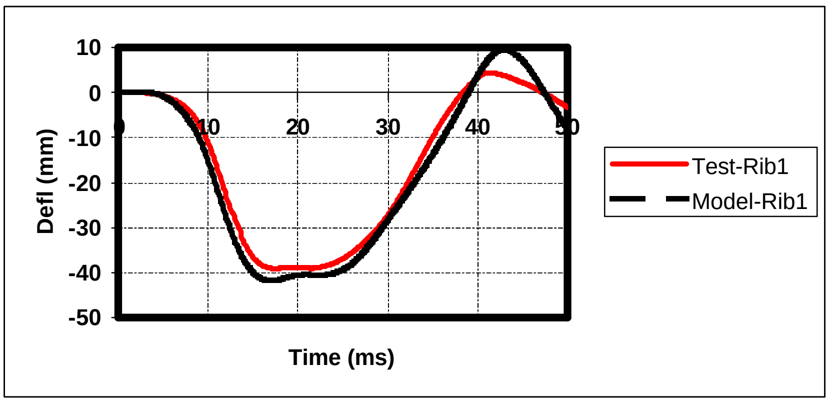


Figure 5. Comparison of rib 1 deflection

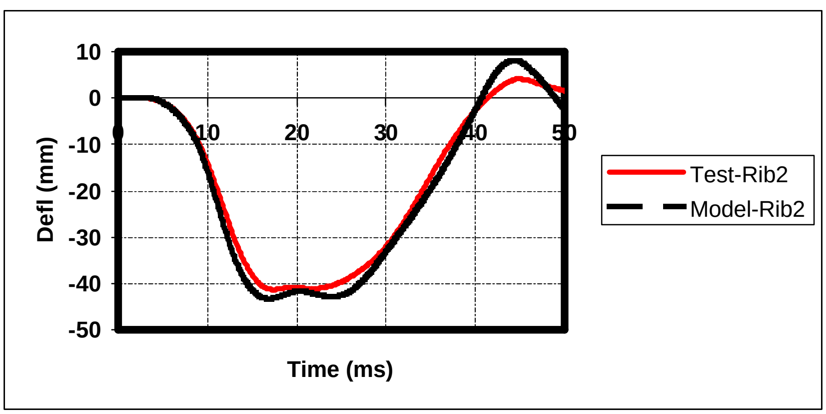


Figure 6. Comparison of rib 2 deflection

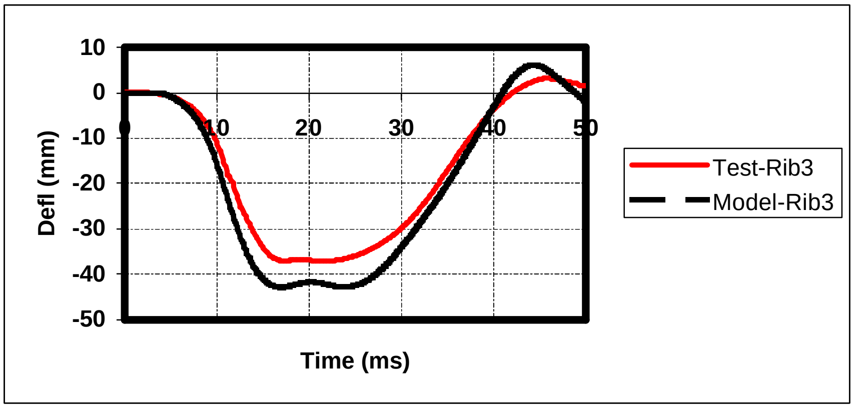


Figure 7. Comparison of rib 3 deflection

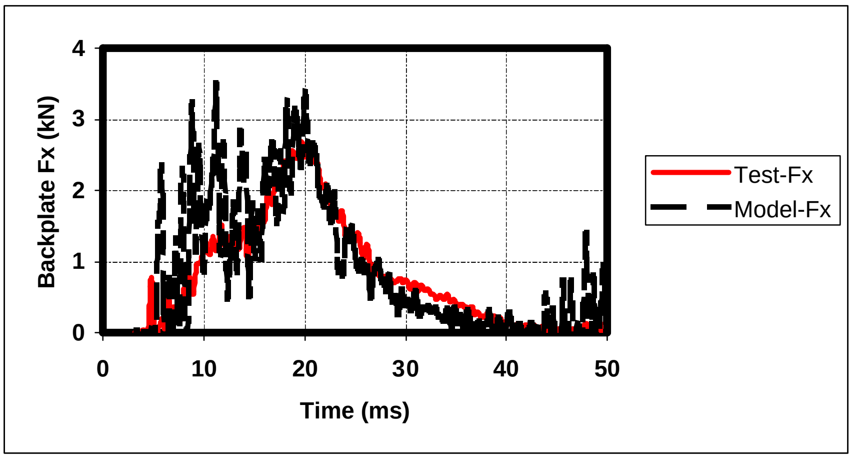


Figure 8. Comparison of back plate force Fx

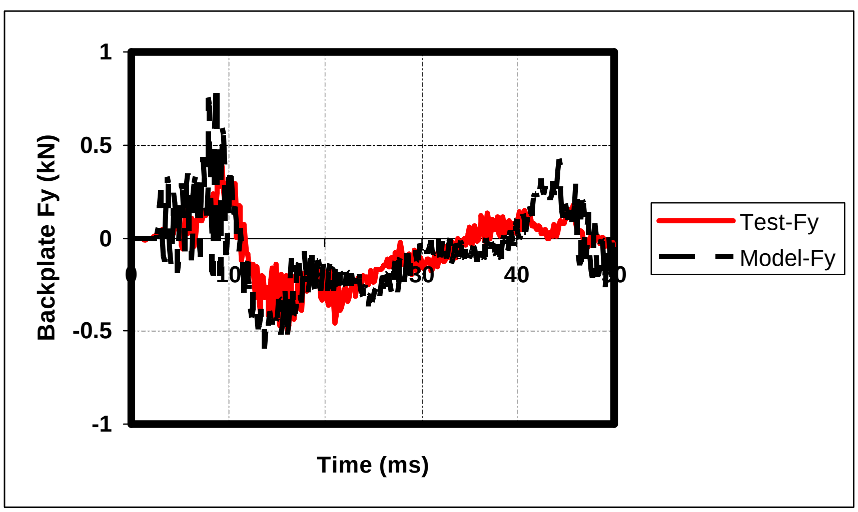


Figure 9. Comparison of back plate force Fy

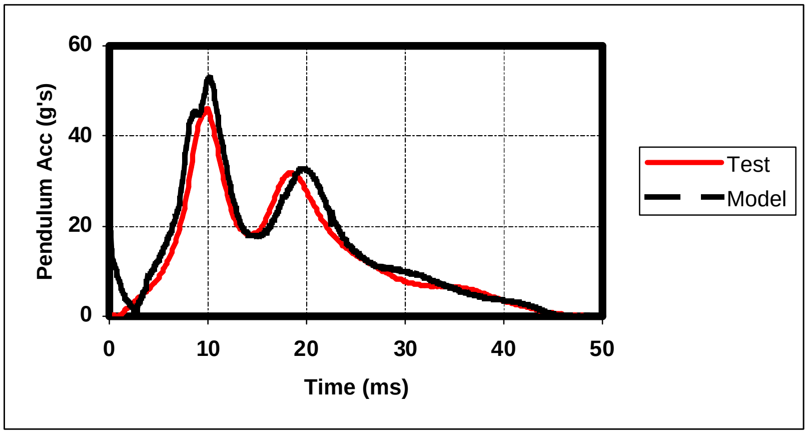


Figure 10. Comparison of pendulum acceleration

As shown in Figures 5 through 10, the model correlates very well with experimental data. The model has sufficient accuracy to analyze the dummy kinematics and the "double-peaks" phenomenon in the rib deflection.

As shown in Figure 10, the pendulum deceleration has two peaks. At 10ms, the pendulum deceleration has the first peak, which is mainly due to the inertial effect of the rib cage. After 10ms, the rib cage starts to rotate about Z-axis due to the offset force from the 45° oblique impact. The lumbar spine is subjected to a twisting moment. The orientation of the pendulum with respect to the rib cage is shown in Figure 3. The rib reaches its maximum deflection at 16ms (Figures 5 through 7). The rib cage continues to rotate and the rib rebounds slightly from 16ms to 20ms. When the rotation of the rib cage slows down at 20ms, the pendulum impacts the rib cage for the second time, as shown in Figure 10. At 26ms, the rib deflection increases slightly to the level of the first peak. Therefore, from 16ms to 26ms, the rib deflection appears to be "flat". The second impact from the pendulum prevents the rib from rebounding. Furthermore, the stiff spring, between the damper cup and the spring locator in the rib, disengages with the rib very quickly, as shown in the spring force (Figure 11). When the rib deflection reaches its first peak at 16ms, the spring has a peak force of 1.3 kN. The spring force decreases to zero at 24ms. Therefore, the damper absorbs the energy and contributes little to the rib rebounding. Detailed model analysis has been conducted and there is no artifact observed. The above analysis shows that the "double peaks" phenomenon is due to the following two reasons:

- Continuously loading (double impacts) from the pendulum to the rib cage.
- Lack of rebounding force from the damper.

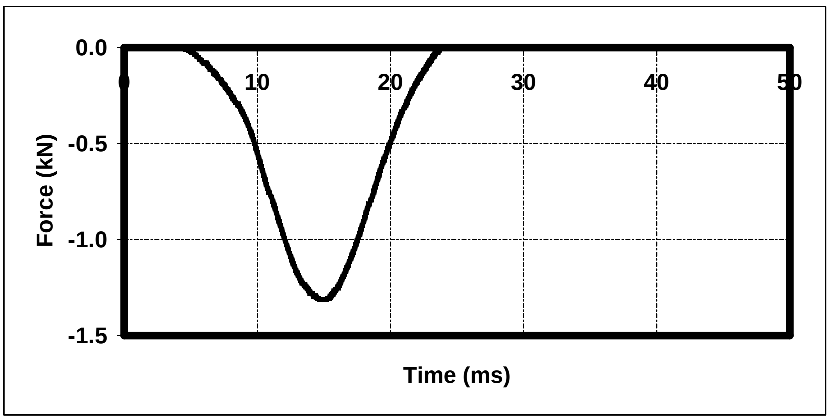


Figure 11. The spring force that applies to the rib in the damper assembly

DISCUSSION

To further demonstrate that the "double-peaks" is not "flat-topping", two additional analyses have been made by changing pendulum initial velocity. The rib 2 deflection and pendulum acceleration are shown in Figures 12 and 13, respectively, for the pendulum impacts at 5.3m/s, 6.7m/s and 8.1m/s. The higher the input energy (velocity) from the pendulum, the more rib deflection is observed. The double impacts can be seen from all three cases (Figure 13). . "Double-impact" can also occur in BioSID for certain impact configurations. Figure 14 shows the rear seated BiodSID upper rib deflection for a side impact test at 33.5mph with a 27-degree crabbed Moving Deformable Barrier, as reported by Chou et al [4]. As shown in the figure, the rib deflection has double peaks. Note that ES2 rib deflection is flatter between the two peaks than BioSID since ES2 damper absorbs more energy due to disengagement from the rib module during rebounding.

The disengagement of the damper from the rib module cannot be considered as an artifact of the dummy. In fact, it simulates the energy absorption from the soft tissue or rib factures of human cadaver. Figures 15 and 16 show typical thorax lateral deflections measured from cadavers in a rigid wall and a padded wall Heidelberg type side impact sled test [5]. The percentage of the thorax compression is obtained by dividing the thorax deflection by half thorax width (laterally). The cadavers had multiple rib factures. As shown in the figure, the thorax absorbed most of the impact energy and did not rebound much for the time period observed.

In the finite element model, the friction coefficient of the linear guidance system for the rib is set to zero. The friction coefficient between the rib extension and back plate is also set to zero. No interference is observed among various parts (pendulum, damper, abdomen, back plate, etc). The analysis rules out any artifact from the dummy.

The rib extension has little deformation. Therefore, the current rib thickness is sufficient.

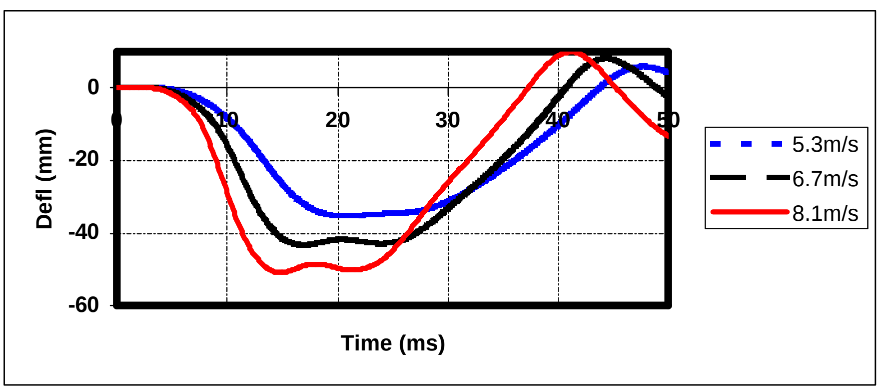


Figure 12. Comparison of Rib 2 deflection for three pendulum velocities

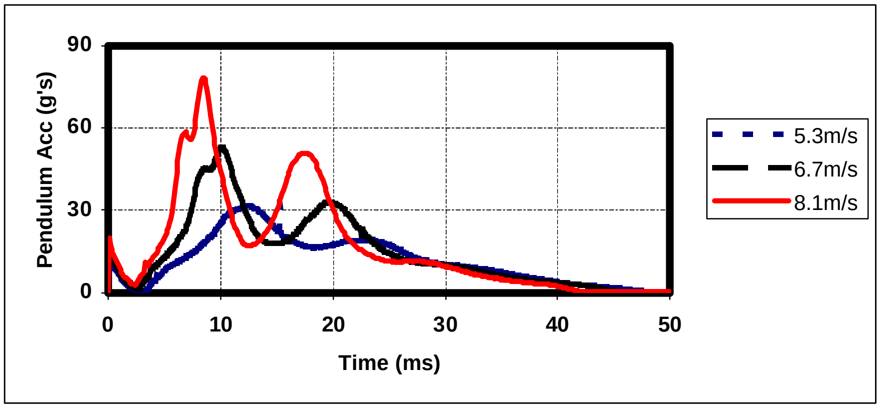


Figure 13. Comparison of pendulum acceleration for three pendulum velocities

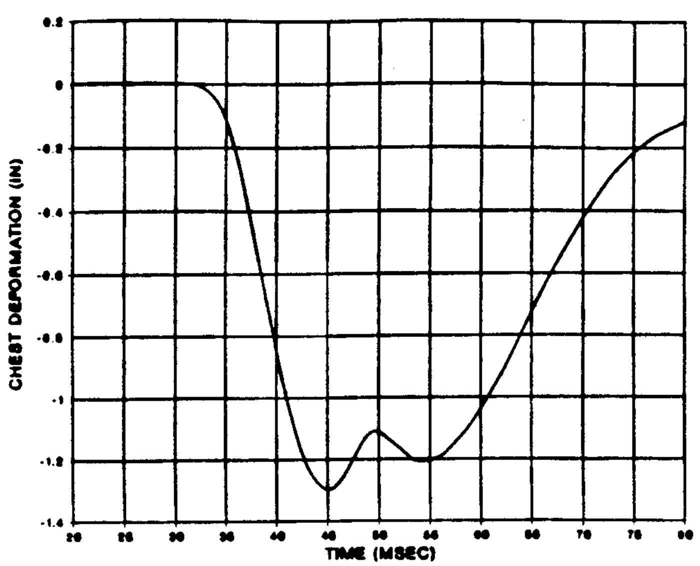


Figure 14. Rear seated BioSID's upper rib deflection reported by Chou et al.

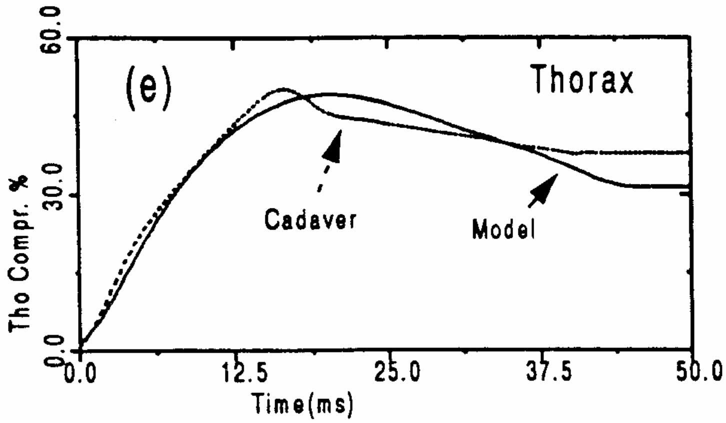


Figure 15. Thorax compression of a cadaver for a rigid wall side impact sled test at 8.6m/s reported by Huang et al.

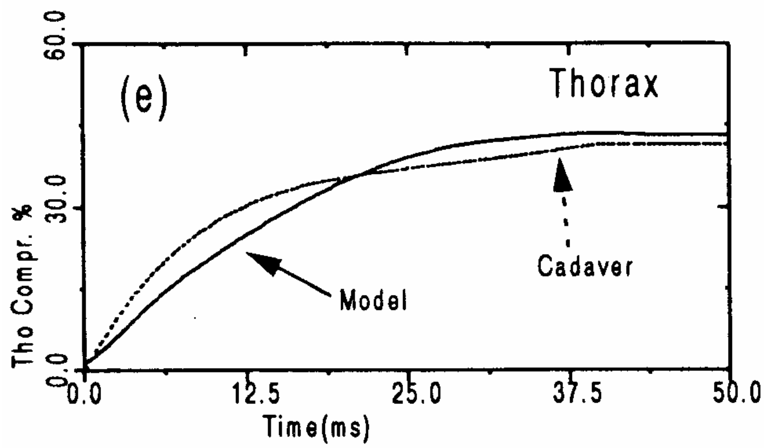


Figure 16. Thorax compression of a cadaver for a padded wall side impact sled test at 8.3m/s reported by Huang et al.

CONCLUSIONS

- The finite element model of ES2 with rib extension correlates well to test data. Additional analysis can be conducted with this model.
- ES2 with rib extension can survive an oblique (-45°) pendulum impact at 6.7m/s. Its rib deflection can discriminate the severity of the impact (e.g. impact velocity).
- The "double-peaks" in rib deflection is due to the double impacts from pendulum and the lack of damper force during rebounding.
- No artifact is observed from detailed finite element analysis.

REFERENCES

1. Huang Y (June 27, 2002), "ES2 Rib Extension Refinement", FTSS internal report.
2. Elhagediab A and Huang Y (August 12, 2002) "Pendulum Rest Results of New ES2 Rear Rib ", Progress Report, FTSS internal report.
3. Elhagediab A and Huang Y (August 14, 2002) "Pendulum Rest Results of New ES2 Rear Rib ", Progress Report II, FTSS internal report.
4. Chou CC, Lin YS, Lim GG (1993) "An Evaluation of Various Viscous Criterion Computational Algorithms", SAE Paper No. 930100.
5. Huang Y, King AI and Cavanaugh JM (1994) "Finite Element Modeling of Gross Motion of Human Cadavers in Side Impact", SAE Paper No. 942207, Proceedings of 38th Stapp Car Crash Conference.

Attachment 2f

ASSEMBLY INSTRUCTIONS

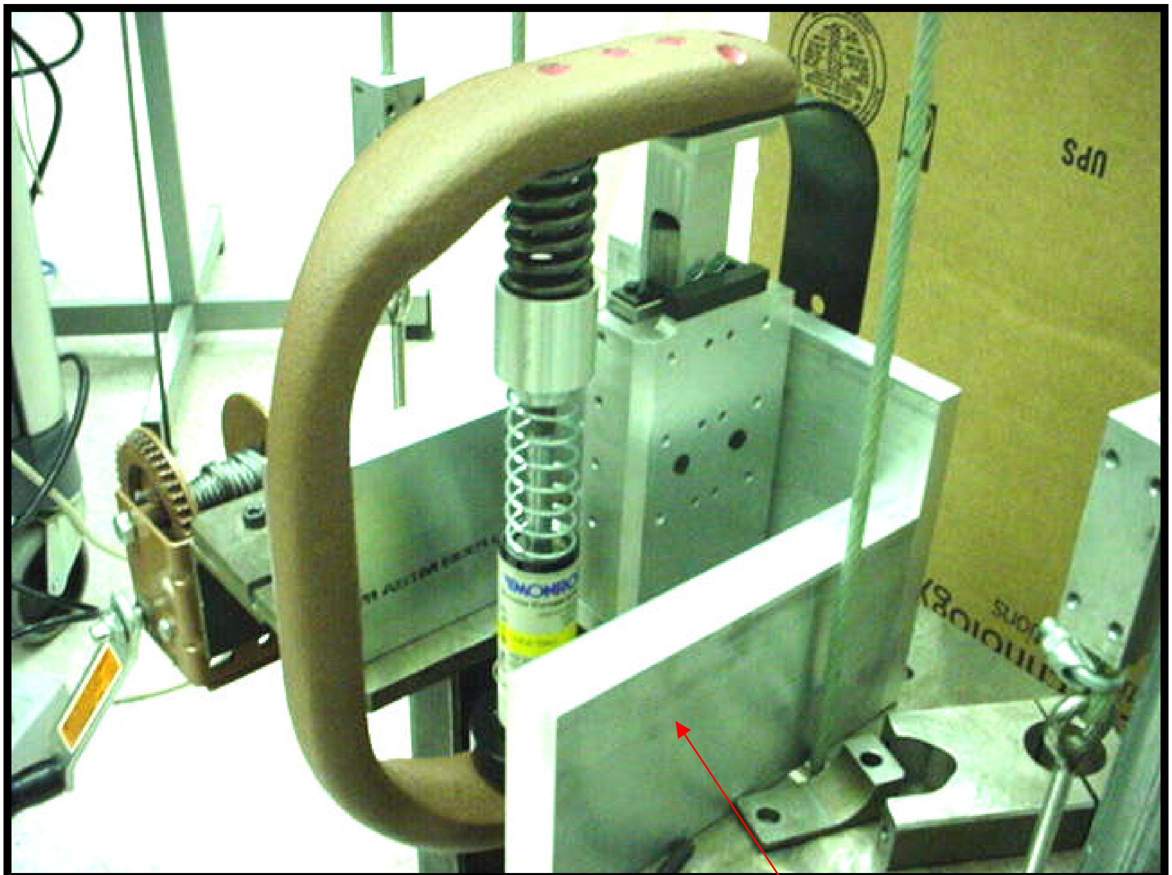
FOR

ES-2

DROP TOWER TEST

November 18, 2002

1. Picture of the drop tower fixture and the EuroSID-II rib module below.

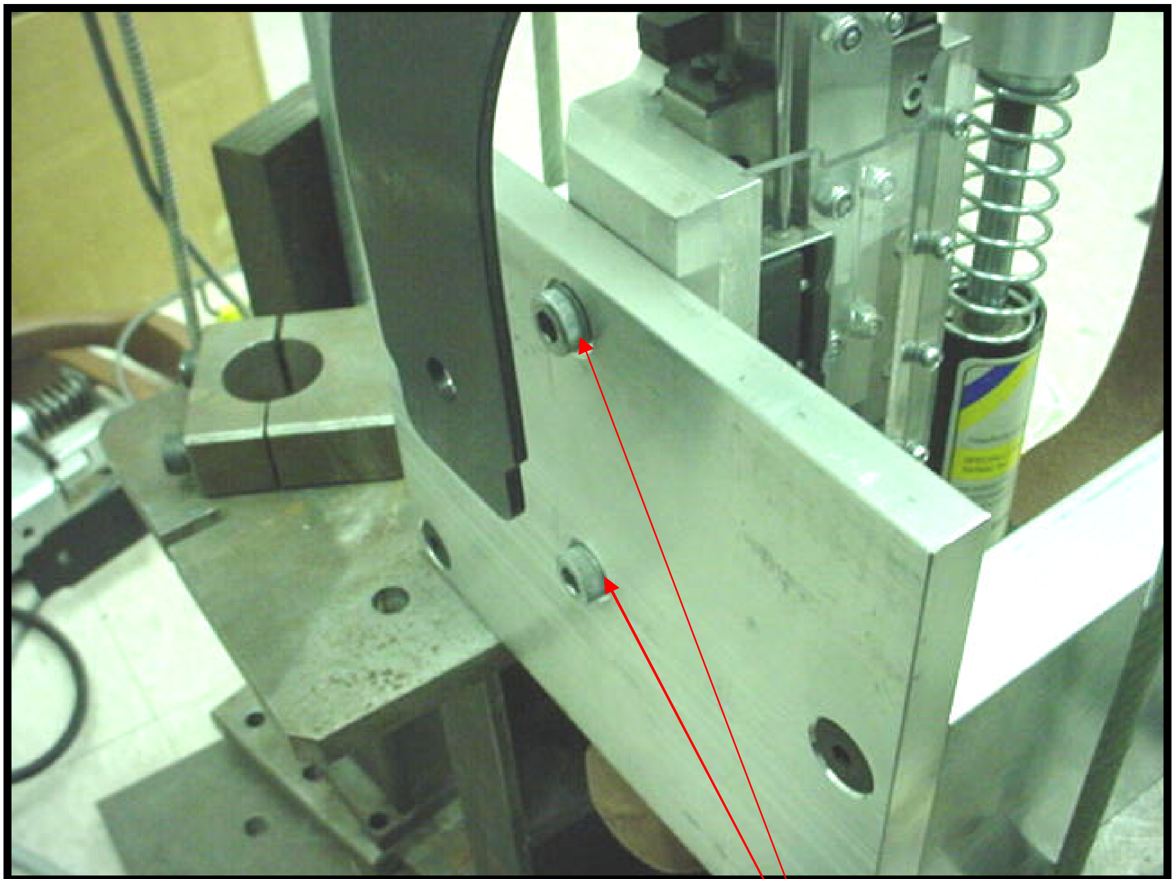


Side support attached to the drop tower base with SHCS 3/8-16 x 1” screw.

As shown in picture above the two side supports on either side of the fixture bracket assembly is attached to the base of the drop tower test fixture using SHCS 3/8-16 x 1” screws.

Note: Ensure that after assembling the rib module on to the fixture, the impactor head should be in line with the linear bearing assembly (piston-cylinder).

2. The rib module assembly is attached to the fixture using two M8 x 20, screws as shown in the picture below.



M8 x 20 screws attaching the rib module assembly to the fixture

ASSEMBLY INSTRUCTIONS

for

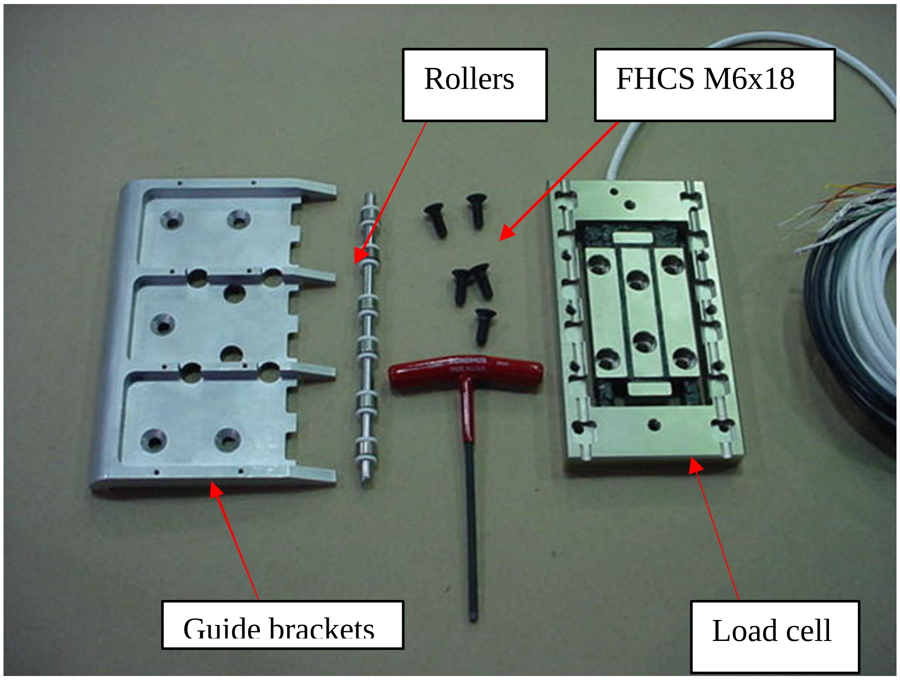
ES-2 Rib Extensions

Rib Modules, Thoracic Spine Box and Load Cell

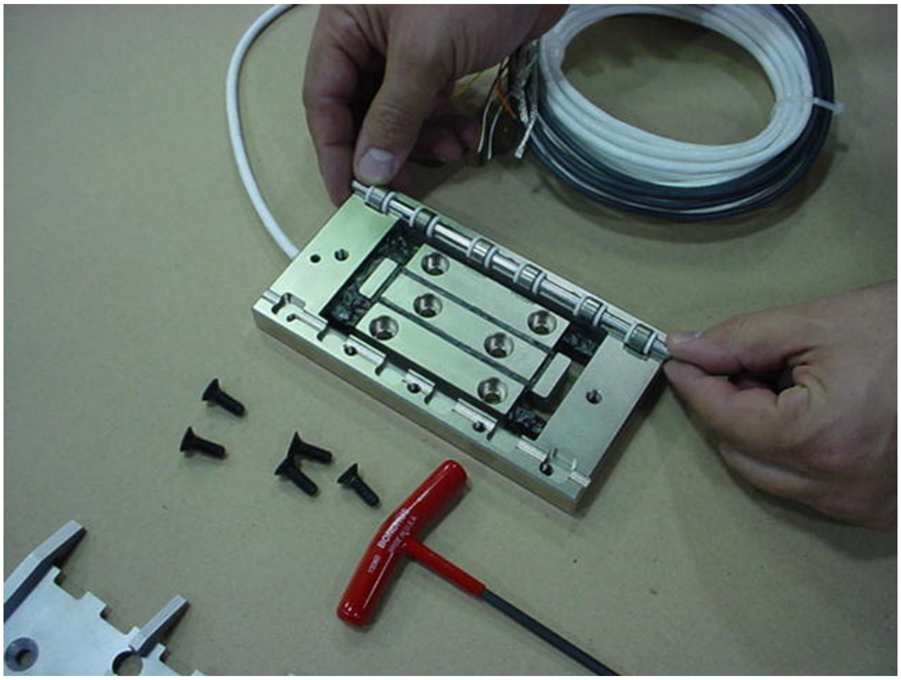
November 19, 2002

I. ASSEMBLY OF THE LOAD CELL, ROLLERS AND GUIDE BRACKETS

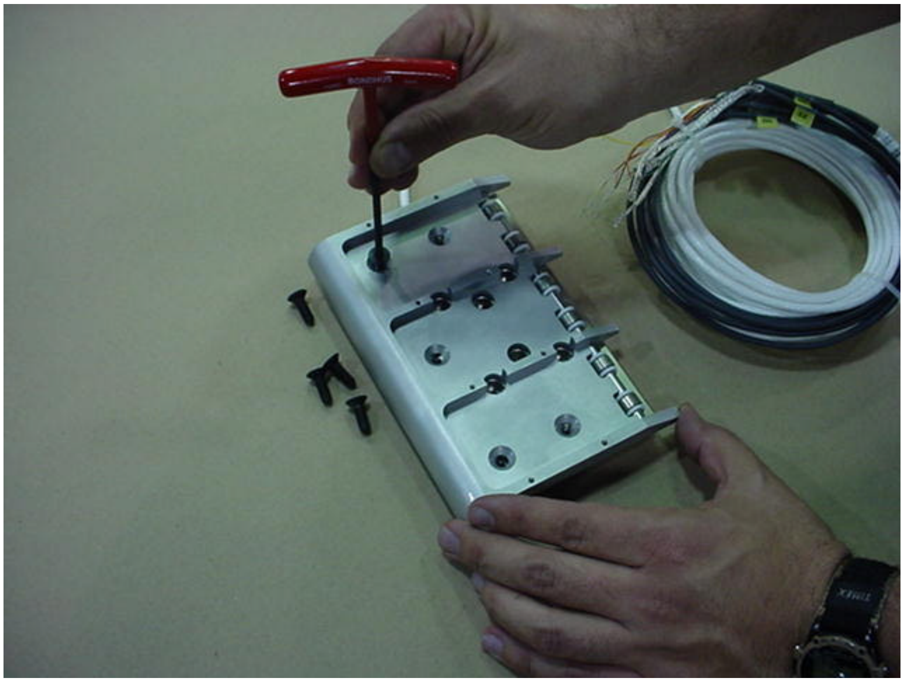
Picture below shows the components required for assembly



As shown in the picture below the roller supports are placed on the load cell

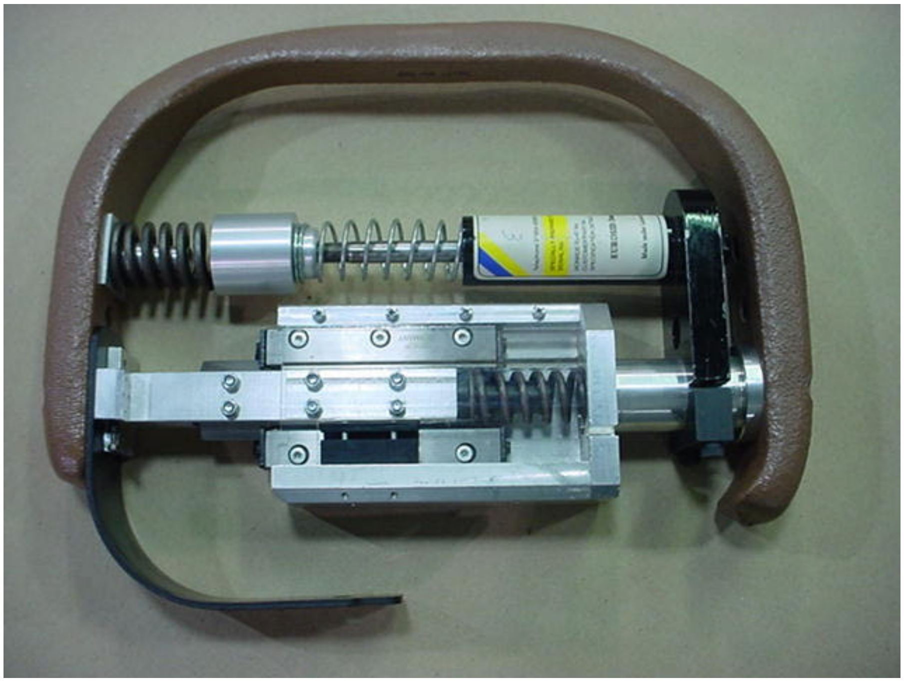


As shown in picture below the guide supports are assembled on to the load cell using FHCS M6 x 18 screws



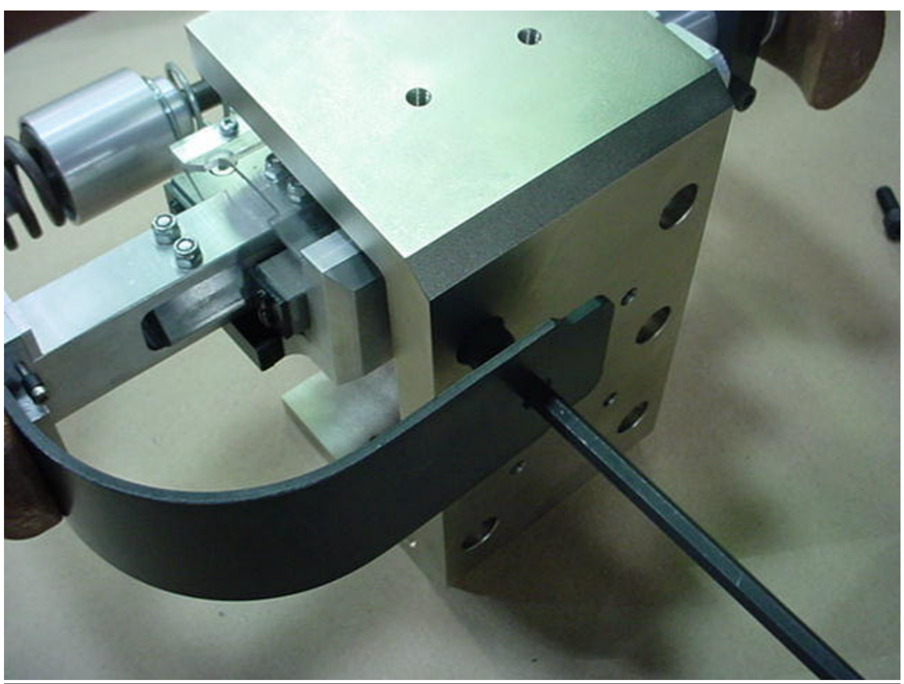
II ASSEMBLY OF THE RIB MODULES TO THE THORACIC SPINE BOX

Picture below shows the EuroSID-II rib module with the rib extension

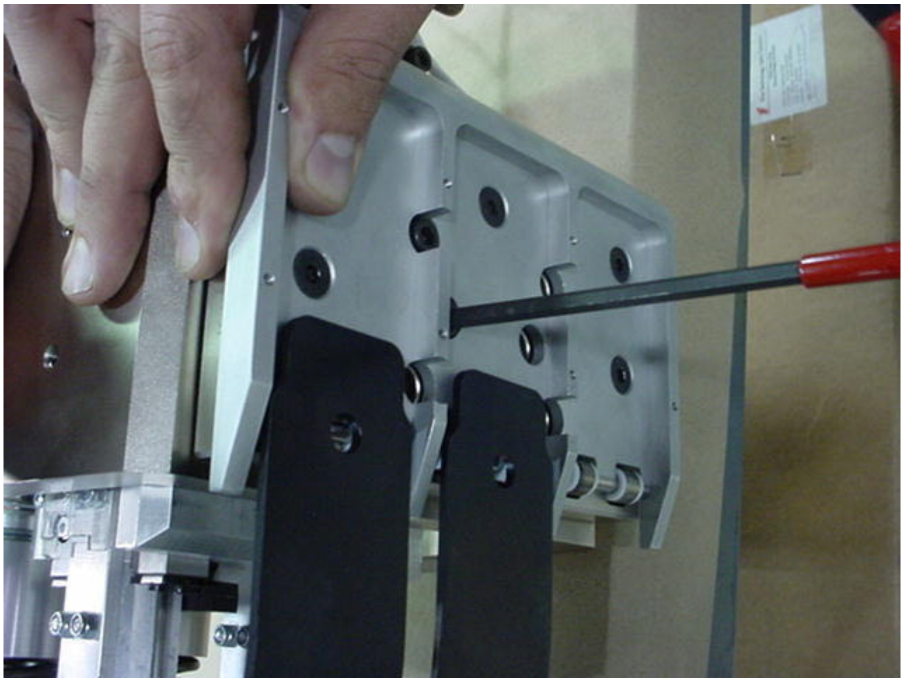


Picture below shows the spine box.

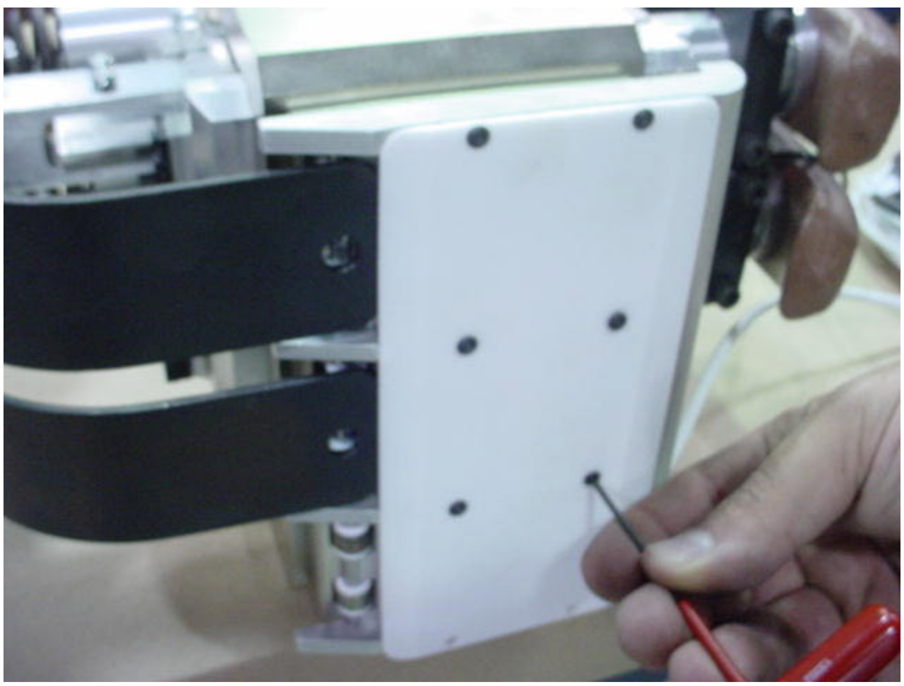
Rib module is assembled on to the spine box using two SHCS M8x20 screws. Note that access hole on the rib extension allows the use of the T-handle wrench to tighten the screw.



Repeat the above procedure until all the three rib modules are assembled on the spine box. The picture below shows only two rib modules (due to non availability of the third module). Assemble the load cell/guide bracket assembly on to the spine box using SHCS M6x20 screws as shown in picture.



As shown in picture below assemble the Teflon cover plate using BHCS M3x6 screws.



Following the above procedure completes the assembly of the EuroSID-II rib modules, load cell, guide bracket and spine box.